INSHORE LAKE MICHIGAN FISH POPULATIONS NEAR THE DONALD C. COOK NUCLEAR POWER PLANT, 1973

By

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Under contract with
American Electric Power Service Corporation
Indiana and Michigan Electric Company

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Special Report No. 52
Great Lakes Research Division
The University of Michigan
Ann Arbor, Michigan
1975

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ACKOWLEDGMENTS

To John C. Ayers, who had confidence in our ability, supported our designs and shouldered some unpleasant tasks so that we could devote our total efforts toward completion of this report, we extend our grateful appreciation. For the continuing successful completion of our activities at the Cook site we would like to extend special thanks to Jon Barnes.

Thomas Bottrell and Ronald Weidenbach, former members of our fisheries group, are acknowledged for their contributions to the study, particularly the field work and data compilation they performed. Summertime assistants James Lee (1973) and Christine Seber (1974) provided invaluable and enthusiastic help. Nancy Thurber deserves thanks for compiling, correcting and organizing figures and tables. We received field assistance from William Yocum, Susan Williams, Erwin Seibel, Bruce Higgins, John Stewart, Donald Robinson, J. C. Ayers, James Roth, Carlos Garcia, Samuel Mozley and Ronald Rossmann.

Robert Purcel of the Bultema Dock and Dredge Co. provided weather data and use of the tug JAMES EDWARDS. Marvin Demerest and Gary DeYoung assisted with field work and built our present on-site laboratory. We thank operations people, particularly shift engineers, for care in handling impinged fish, and Robert Bishoff and Rudy Gordine for providing water circulation data. Captain Edward Dunster and First Mate Earl Wilson of the R/V MYSIS are acknowledged for their help in the completion of trawling activities. Lloyd Mollhagen, Jr. and Larry Rosenthal set gillnets for us during winter months.

Theodore Ladewski deserves special acknowledgment for his suggestions and help in computer programming and data analysis. Edward Johnston, James Kubus and Andrew Schaedel also helped on many occasions. We thank our librarian, Donald Munro, for his efforts in theses procurement, and Barry Mulder for providing stomach content data. Also deserving thanks is Margaret Everett for reading and editing this report and offering many helpful suggestions on style and form. John C. Ayers and Erwin Seibel also read and criticized the text. We thank H. E. Ayers in a special way for typing the report and Janine Graham for typing many of the tables.

We are also indebted to LaRue Wells and Stanford Smith, who read through the manuscript and offered valuable suggestions on subject matter based on their extensive experience in research on Lake Michigan fishes.

GENERAL INTRODUCTION

This report concerns preoperational fish monitoring data gathered during 1973 in the area around the Donald C. Cook Nuclear Plant (2,200 megawatts) located on the shores of southeastern Lake Michigan near Bridgman, Mich., in Berrian County. Initial "on-line" status for Unit 1 (1,100 megawatts) is expected during February-March 1975.

Fish collection activities during the preoperational year 1973 were directed toward standardizing collection techniques used in 1972, the first year of fish monitoring, as well as establishing new techniques suggested by previous errors and experience. At present we use trawls, seines and gill-nets to collect adult and juvenile fishes, and No. 2 plankton nets to collect fish larvae, from which we hope to establish baseline abundance indices, length-frequency histograms and temperature-catch relationships, against which postoperational monitoring data can be compared.

Some data from the first year (1972) of preoperational fish monitoring (Jude et al. 1973) as well as some collected during 1974 are included in the present report to clarify speculative 1973 data or corroborate 1973 findings.

In view of the recent disturbances in the complex of fish species in Lake Michigan and their interaction with an ever-changing environment, detecting the effect of yet another input into the ecosystem demands as clear and accurate a picture as can be obtained of the present status of the fish populations, what the natural range of variation in numbers can be, and how fishes found in the inshore environment relate both distributionally and seasonally to other parts of the lake. To do this we have initiated a multi-faceted research effort, directed at fish from egg to adult, to define within the range of present technology the "normal" biology of each species found. Since we could not do lake-wide sampling of fishes, we have supplemented our own experiences and knowledge with extensive literature reviews to fill in the distribution and biology of each species.

Postoperational sampling will determine if fish at stations directly off the Cook Plant will be affected by plant operations. Because some stations coincide with the discharge and intake structures, any possible future pumping effects should be more easily detected. More susceptible species can be determined by comparing field-caught fish with those found on the travelling screens. Sampling at beach stations will detect plume effects, if any, on surf-zone fishes. We have set up control stations (reference locations at Warren Dunes) to detect natural changes in fish populations, so that it will be possible to discriminate between natural and possible plant-induced changes at the plant site during postoperation.

This report is divided into four sections plus a general introduction and summary. Each of the four sections was written to be an entity of itself, having an introduction, results, and a methods and discussion section where appropriate. One literature-cited section serves the whole

report. Considerable referencing of other sections was done when necessary to corroborate and relate the various phenomena under investigation within one section. The first section is a statistical design overview and critique of the methods we tried and those eventually used, as well as a discussion of catch data (distribution, zero data, etc.) and problems encountered. It is hoped that others will benefit from our experience.

The second section is a discussion of the biology of the 45 fish species (adults and juveniles only) captured during 1973 in the Cook Plant vicinity, including seasonal, diel and horizontal distribution for inferred age groups, spawning times (from our data and literature reviews) and temperature-catch relationships obtained from field data.

The third section discusses seasonal, horizontal, vertical and diel occurrence and distribution of fish larvae (fish less than 25.4 mm total length) in the Cook Plant area. Distribution of fish eggs is also included. A discussion of net selectivity, migratory behavior and competition among larvae puts this important life stage into perspective with the adult and juvenile fish biology section. Nursery areas and some indication of spawning times were also obtained from these data.

The last section is concerned with impingement (fish entrapped on the intake travelling screens) and entrainment (fish eggs and larvae passed through the travelling screens and condensers and subsequently discharged back into the lake). Since the Cook Plant has not yet gone "on-line," impingement data are scant, but some indication of the species and numbers of fish that might be impinged was obtained from routine test pumping of one of the seven circulating water pumps (9.45×10^5 l/min - 2.5×10^5 gal/min) about once a month.

The recent proliferation of nuclear power plants in the United States, and particularly on Lake Michigan, has caused concern on the part of ecologists and the general public alike as to possible effects of these plants. Surprisingly little data, however, have been accumulated regarding actual effects on fish by nuclear power plants--whether by heated discharges, entrainment or impingement. We believe that our studies at Cook will help clarify some of the now cloudy areas of concern and provide actual data, so that possible effects of the plant can be determined.

SECTION A

EXPERIMENTAL DESIGN AND STATISTICAL CONSIDERATIONS FOR MONITORING FISH POPULATIONS

Donald J. Stewart and Paul J. Rago

INTRODUCTION

The number of years required to evaluate the environmental impact of a thermal discharge plume depends on the magnitude of any possible change, inherent variability of the natural system compounded by sampling error, and the number of observations that it is feasible to make within a given period. Previously, little thought has been given to what quantitative changes in fish populations a particular sampling program might be able to detect; least detectable changes are estimated herein for the Cook Plant study. Need for such information is a recent outgrowth of environmental concern and associated legislation. Studies similar to the Cook Plant study are under way or being planned, and guidelines for design of such studies are now being drafted and may become mandatory through legislation (T. Edsall, personal communication, Great Lakes Fishery Laboratory, U. S. Fish and Wildlife Service, Ann Arbor, Mich.).

The objective of this section is to give a critique of the experimental design for the Cook Plant fisheries investigation based on one complete year of field studies. For our benefit, this analysis is intended to identify problems or deficiencies in the existing program which might be corrected as we begin our final year of background studies. It is hoped that others might also benefit from our self-criticism.

The focus of this section is on species abundance indices being developed to quantify changes in species populations which might be attributed to Cook Plant thermal discharges. To develop abundance indices for all important species and various life-history stages of each, four different gear--trawls, gillnets, seines and plankton nets--are being used, and the sampling programs are considered below with greatest emphasis on the trawling program. As each sampling gear has its unique biases, data from different gear cannot be directly compared but in fact are overlapping and complementary. Each sampling program should be considered a separate experiment to assess the impact of Cook Plant discharges upon some aspects of fishes in the thermal plume.

Given that abundance indices are used, this study is based on the premise that catch-per-unit-effort has a direct linear relationship with fish abundance. Standing crops of fish in the study areas are not quantified except for fish larvae from plankton net samples where a known volume of water is sampled.

TRAWLS

The Cook Plant study trawl data from 1973 are better suited for statistical analysis than either gillnet samples, which were too costly to replicate in terms of time and manpower available, or beach seine samples, which were technically difficult to replicate exactly at different stations and under varying weather conditions. The basic experimental design for trawls consists of duplicate samples taken both day and night at 6.1 and 9.1-m depths off the Cook Plant (experimental area) and off Warren Dunes (control area) on a monthly basis from April through October. November samples are lacking because of bad weather. In 1973 the above program was completed with only 2 of 112 (56 duplicate) observations missing due to gear problems.

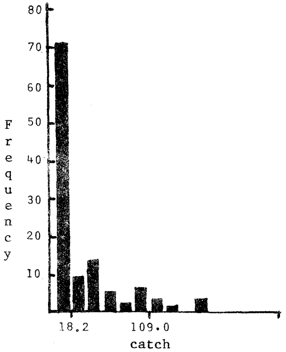
Effects of thermal discharges from the Cook Plant could first become evident in 1975. Continuing the above trawling program through 1976 will give 2 years preoperational data and 2 years operational data that, as a minimum, should be adequate to determine acute impacts of thermal effluents upon the fish community. Thus, the completed experimental design will be a 5-way analysis of variance (ANOVA) with fixed effects (Model I) in a completely crossed design (2 times of day) x (2 depths) x (2 areas) x (7 months) x (4 years) with 2 replicates per cell. Two years of follow-up data are considered herein for discussion only; ultimately, more than 2 years of operational data will be taken.

The primary objective of this trawl data analysis is to determine the least detectable true changes in fish populations. Given the existing experimental design and variation inherent in sample estimates, will the sample program accomplish its purpose?

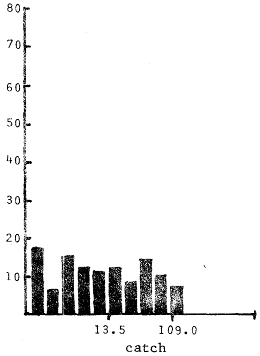
There are three secondary objectives of analyzing data at this early stage in the experiment: 1) to examine distributional properties of the trawl data and transformations of the data to determine if a parametric analysis of variance would be valid, 2) to test assumptions of the ANOVA model, and 3) given satisfactory results from the foregoing, to perform an ANOVA to identify biological phenomena which may be worthy of supplementary field effort in our last year of baseline data collection. Statistically significant main effects and interactions between various ANOVA factors might be expected to reflect a chronology of events over the year, such as spawning migrations as well as persistent population differences between areas and diurnal behavior patterns.

DISTRIBUTIONAL CHARACTERISTICS OF THE TRAWL SAMPLE DATA

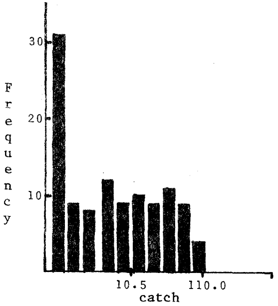
The ANOVA model outlined above must be considered for each species separately. Data for a species design matrix, expressed as number of fish per 10-min trawl haul, proved to be extremely skewed to the right for all species considered. A frequency histogram for number of fish per trawl haul is exemplified by that for spottail shiners (Fig. A1); the illustrated density function had the following properties: $N = 110$ (2 missing observations), $\overline{X} = 28$, $s = 40.74$ and $s^2 = 1659.75$. The coefficient of dispersion, $s^2/\overline{X} = 35$,



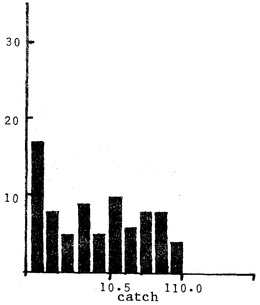
Raw data for spottail shiner; April-October, n=112.



$Log_{10}(X+1)$ transformed data for spottail shiner; April-October, n=112.



$Log_{10}(X+1)$ transformed data for yellow perch April-October, n=112.



$Log_{10}(X+1)$ transformed data for yellow perch; June-October, n=80.

FIG. A1. Frequency histograms for trawl catches of spottail shiners and yellow perch from the Cook Plant study areas in 1973. Catches are expressed as number of fish per haul.

indicates a contagious distribution (Sokal and Rohlf 1969), and the coefficient of variation, $CV = s/\bar{X} \times 100\% = 144\%$, is comparable to that for catch-per-trawl-tow data observed in a study of fish populations on Georges Bank (Taylor 1953). In the latter study the density function was found to conform to a negative binomial distribution, and $\log (X + K/2)$ was indicated as an appropriate transformation to normalize data for analysis of variance. In this case, K is the exponent in the negative binomial function and is a measure of the contagion of the distribution.

For the present analysis, the customary empirical transformation $\log_{10} (X + 1)$ was used to normalize the data (Fig. A1) and to stabilize error variance. The ongoing analysis of Cook Plant data will eventually include a goodness-of-fit test of the hypothesis that the trawl data are distributed according to the negative binomial; it would also be valuable to compare results of ANOVAs calculated with the two transformations given above.

Parameters comparable to those presented for spottail shiners were calculated for four other species--alewife, rainbow smelt, yellow perch and trout-perch. These four species also had contagious distributions, which for the present analysis are assumed to be negative binomial (Table A1).

Fish are mobile organisms with complex behavior patterns. Distribution in the study area can change seasonally and perhaps even diurnally, thereby affecting observed frequency distributions of catch data. To test the possibility that we may not be sampling comparable distributions at different times and places, frequency histograms and coefficients of variation (CV) were examined for various stratifications of the data. Almost without exception frequency distributions were strongly skewed to the right as in Figure A1. For example, when spottail shiner data were stratified by month, depth and area, CVs ranged from 34% to 150% with an average for the 28 strata of 102%. Comparable average CVs for other species considered were alewife 116%, rainbow smelt 88%, yellow perch 112% and trout-perch 96%. Observed catch frequencies in all cases indicated contagious distributions, and the chosen transformation $\log_{10} (X + 1)$, is considered appropriate for all stratifications of the data.

Too many zero observations (no fish caught) in the design matrix can cause problems, since $\log_{10} (0 + 1) = 0$ and the transformed data might be bimodal with peaks at zero and at the geometric mean of the distribution (Fig. A1). To moderate problems which may arise through violation of the normality assumption of the ANOVA model, only those species with few zeros in their design matrix were included in the analysis. Inspection of frequency histograms of transformed data suggested that more than about 20% zero observations gave a noticeably bimodal distribution. The five most abundant species in the trawl catches had the following percent zeros ($N = 112$ with two substitutions): alewife 13%, spottail shiner 15%, smelt 9%, yellow perch 28% and trout-perch 21%. Most zero observations for yellow perch and trout-perch occurred during April and May. Deletion of these two months from the ANOVA design matrix for these two species increases confidence in whatever inferences are drawn from the analysis but reduces the scope of the inferences. The reduced matrices ($N = 80$ with one substitution) have 14% zeros for both species, and the data more closely approximate a normal

TABLE A1. Comparison of distributional properties of 1973 sample data for the most abundant fish species caught in trawls, gillnets, beach seines and plankton nets near the Cook Plant, southeastern Lake Michigan.

Gear	N	$\bar{X}$	Standard deviation (s)	Coef. of variation $(s/\bar{X})$ 100	Coef. of dispersion $(s^2/\bar{X})$	% zero data
TRAWL[1] (APR-OCT)						
Spottail	110	28	40.74	144	59	15
Alewife	110	108	170.34	158	269	13
Rainbow smelt	110	119	245.35	206	507	9
Yellow perch	110	15	22.96	152	35	28
Trout-perch	110	29	56.06	195	109	21
GILLNET[2] (APR-OCT)						
Spottail	74	54	67.44	126	85	11
Alewife	74	186	216.64	116	251	10
Rainbow smelt	67	8	18.74	239	45	48
Yellow perch	74	31	48.49	155	75	24
Trout-perch	74	4	10.72	240	26	54
SEINE[3] (APR-OCT)						
Spottail	83	164	394.73	240	974	14
Alewife	83	1505	5009.60	333	16673	30
Rainboe smelt	83	30	114.31	380	434	70
Yellow perch	83	8	23.08	306	71	71
Trout-perch	83	1	2.94	309	9	82
PLANKTON NET (JUN-JUL)						
Alewife	88	2927	5577.80	191	10630	7

[1] Two missing observations.

[2] The basic design matrix has 56 observations; 11 and 18 supplementary gillnet samples are included respectively for smelt and the other four species. Supplementary samples were primarily taken off Cook Plant.

[3] One missing observation.

distribution as illustrated by the frequency histogram for yellow perch (Fig. A1). Other fish species were relatively uncommon and only small subsets of their design matrices might be useful for statistical analysis; they are excluded from the present analysis. However, exclusion of uncommon species from statistical analysis at this early stage in the experiment does not preclude their inclusion when more data become available.

THE ANALYSIS OF VARIANCE

Having narrowed the analysis to include only taxa and months where data can be approximately normalized by transformation, we may proceed with improved confidence that the data are amenable to parametric analysis, but other assumptions of the model remain to be considered below. To summarize the foregoing, the ANOVA factors and their levels to be analyzed are as follows:

	Factor	No. of levels	Levels
1.	Time of day	2	Day, night
2.	Depth	2	6.1 m, 9.1 m
3.	Area	2	Cook Plant Warren Dunes
4.	Month	7 alewife spottail shiner rainbow smelt	April - October
		5 yellow perch trout-perch	June - October
5.	Year	Not included in these ANOVAs, since so far only one year of complete data is available (1973).	

A four-way ANOVA (Model I) in a completely crossed design was performed using the first four factors for each species. Two computer programs of the UCLA Biomedical series (BMD2V and BMD8V) available through the Statistical Research Laboratory at the University of Michigan were used. Results and discussion of these analyses are presented in Section B of this report under discussions of each species. The ANOVA method that was used can be termed an unweighted means analysis of unbalanced data. This method is appropriate in our case as the missing observations were due to essentially random events (Winer 1971, p. 402). In brief, the method entails running the analysis on the data matrix with cell means substituted for missing values. The computed numerator sums of squares are then adjusted downward through multiplication by the ratio n_h/N, which is the harmonic mean cell size divided by the maximum cell size. The number of substitutions is subtracted from the degrees of freedom for the denominator sum of squares. This method is described in a document issued by the Statistical Research Laboratory of the University of Michigan (Fox 1973). The ratio n_h/N was 0.966 for alewife, spottail shiner and rainbow smelt (2 missing observations); it was 0.976 for yellow perch and trout-perch (1 missing observation).

ASSUMPTIONS OF THE ANOVA MODEL

To test the assumption of normality of the errors, a frequency histogram of the residuals (e_{ijklm}) was examined from the ANOVA of the transformed data for each species. As there were only 2 observations per cell, these distributions were all symmetrical about a mean of zero. The relatively high percentage of zero or near-zero observations in most cases gave a noticeable peakedness (leptokurtosis) to the distribution. Reducing yellow perch and trout-perch to a 5-month data matrix reduced the peakedness for these species. Violation of this assumption has little effect on inference about means (Scheffé 1959).

The assumption of equality of variances of the errors was tested by scatter-plotting residuals against cell means for each species. In all cases this assumption appeared to be met reasonably well. It is interesting to note, however, that for alewife and rainbow smelt high mean values tended to have less variation than intermediate values. This suggests a patchy distribution which is smoothed out by the sample size as fish density increases and is not too unreasonable for schooling fish.

The final assumption of the ANOVA model to be considered, and most serious with respect to inferences about means, is statistical independence of the errors (Scheffé 1959). A problem might arise if replicate samples are taken without replacement over exactly the same bottom area. In this case, reduction in numbers of fish caught by the first haul would give a consistently lower catch on the second haul. The same effect might be realized if the boat and net created a disturbance that frightened fish away from the station. Finally, if too many resident fish are removed from the study area, there could be an unnatural downward trend in catch over months or years.

As a test for independence between replicate trawls, each of the 56 pairs was scored a +, 0 or - depending on whether the second trawl haul was greater than, equal to, or less than the first. If the replicates are independent samples from the same population, the ratio of +s to -s should be about 1 to 1.

In fact, further analysis has revealed seasonal trends in the data that may be inherent in the trawling methodology and that would mask any effects due to non-independence between replicates. Most species were found to be onshore-offshore migrants rather than residents of the study areas, so month-to-month sample independence was difficult to test. Given the difficulties of testing the independence-of-errors assumption, the obvious solution is to make a direct effort to avoid sweeping the same area twice. Care should also be taken not to overfish the areas under investigation.

SEASONAL TRENDS IN THE TRAWL DATA

Pooling the above +:- data by species and station and stratifying by month, seasonal trends in the data were indicated. During April and more so in June, there was a tendency for +s. From July through October the tendency was for -s (Table A2).

TABLE A2. Relationship of first to second trawl haul of 56 replicate pairs taken in the Cook Plant study areas from April through October 1973. First hauls were always taken from north to south and second hauls from south to north; +, 0 and - indicate that the second haul was greater than, equal to or less than the first with respect to number of fish caught for each of five species.

	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTALS
SPOTTAIL SHINER								
Cook Plant	+-0-	0++-	++++	+-+0	---0	----	----	9:15:4
Warren Dunes	0+--	-+++	0-00	---0	++-+	+0--	++0+	11:10:7
							total	20:25:11
ALEWIFE								
Cook Plant	-+-+	0+0+	++++	-+++	--+0	+++0	-+-0	16: 7:5
Warren Dunes	0--+	0-0+	+---	----	+-++	-0+-	+++-	10:14:4
							total	26:21:9
RAINBOW SMELT								
Cook Plant	++++	++++	0-++	0-+-	+--+	+-+-	----	15:11:2
Warren Dunes	0+-0	----	+++-	000-	--+-	-0++	---+	8:14:6
							total	23:25:8
YELLOW PERCH								
Cook Plant	000+	0-0-	+--+	-++-	+-++	--+-	0---	9:13:6
Warren Dunes	0+0-	0-0-	--0+	---0	----	-0++	0-00	4:14:10
							total	13:27:16
TROUT-PERCH								
Cook Plant	000+	0--+	-0++	0+--	-+--	--+-	+-0+	9:12:7
Warren Dunes	0+0-	+-0-	+++-	+-+-	-+--	-0++	+-++	13:11:4
							total	22:23:11

MONTHLY TOTALS +:-:0

	APR	MAY	JUN	JUL	AUG	SEP	OCT
C.P.	9: 4: 7	9: 5: 6	14: 4: 2	9: 8: 3	7:11: 2	7:12: 1	3:14: 3
W.D.	5: 7: 8	5:10: 5	8: 8: 4	2:13: 5	8:12: 0	8: 7: 5	10: 6: 4
TOTAL	14:11:15	14:15:11	22:12: 6	11:21: 8	15:23: 2	15:19: 6	13:20: 7

First and second trawl hauls were always taken respectively going south then north and were taken parallel to shore. Currents, wind and waves are consistently present in the study areas and are especially strong in the fall. As trawl hauls were made for 10 min at a fixed r.p.m., going with the prevailing weather and currents would conceivably sample a larger bottom area than going against the currents. If one accepts this premise, then systematic patterns in the relationship of first (to the south) and second (to the north) trawl hauls can be expected when prevailing weather and currents exist.

Relative efficiency of the trawl when fished with or against currents of various strengths is unknown. It is known, however, that large fish such as salmon are rarely caught at the trawling speeds used and can probably swim out of the net. As boat and net are slowed by wind, wave and current resistance, escapement should increase. Thus fishing efficiency relative to current direction may compound the disparity between replicates which can result from sweeping different areas of bottom in opposite directions.

Pooling the +:- data by species and stratifying by month and area (Cook Plant vs. Warren Dunes), expected patterns emerged. Comparison of monthly +:- ratios for the two study areas (Fig. A2) suggests that the

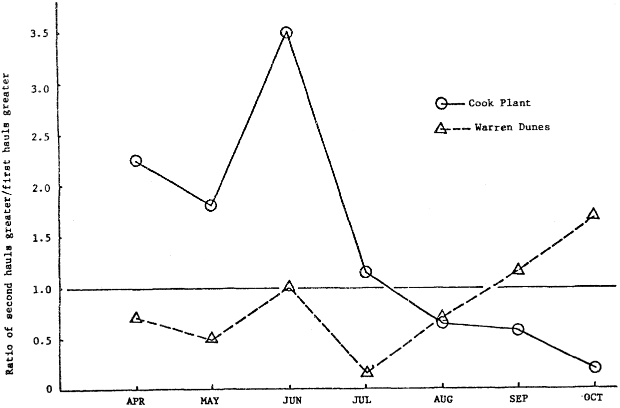


FIG. A2. Seasonal changes in the relationship of first trawl to second trawl haul in two areas of southeastern Lake Michigan, first trawl going north to south, second trawl always going south to north.

two areas are influenced by different current patterns which prevail in opposite directions. Further, both systems seem to reverse their direction in August while maintaining their antagonistic relationship.

Further indications of the trends just mentioned are evident when one examines the original +, 0, - matrix (Table A2) for strings of consecutive +s or -s. Spottails off Cook Plant had all +s in June and almost all -s from August through October. Alewife showed a string of +s off Cook Plant in June and July with opposing -s off Warren Dunes during the same months. It might be noted that these more consistent patterns occurred during spawning seasons when the density of adult fishes is highest in the study areas, suggesting that seasonal trends (Fig. A2) could be even more evident if all species were always present at spawning time densities. As with alewife, smelt showed a string of +s off Cook Plant during their spawning period, April and May, with opposing -s off Warren Dunes in May. Yellow perch showed a string of -s off Warren Dunes in July and August. Trout-perch, the species which was overall least abundant of those considered, had no noticeable trends.

If in fact trawling with the current gives larger catches, then it might be concluded that the area off Cook Plant is influenced by prevailing south to north currents in April through June and increasing north to south currents from August through October. The pattern for Warren Dunes would be just the opposite. Currents are emphasized here because wind and wave direction are likely to be similar in both study areas for a given sample period.

STATISTICAL IMPLICATIONS OF THE TRENDS

What are the implications of these seasonal trends and area differences for the validity of inferences drawn from the experimental design? Seasonal trends in the relation of first to second haul catches are believed due to always taking first and second trawls going south then north. It is thought that trawling speed and perhaps differential fishing efficiency give larger catches when going with the current. Moreover, stronger currents should give relatively greater disparity between catches in replicate trawls. As long as one trawl haul is made in each direction, average bottom area swept and average fishing efficiency would be approximately the same for all stations and months. Thus inferences drawn from the ANOVA model, which compares means, will still be valid, but the error variance will be increased somewhat by the non-independence of the replicate catches.

A normal approximation to the binomial distribution (Zar 1974, p. 287-290) was used to test for the hypothesized 1:1 ratio of +s to -s. Data were stratified by species (area and month pooled). The test showed no significant deviations ($p<.01$) from the 1:1 ratio for all species tested. For yellow perch, however, the ratio +:- was 13:27. The test statistic Z was 2.194, which was greater than $Z_{.05}$(= 1.96) and close to the critical value $Z_{.01}$ (= 2.576). This suggests that other factors may be influencing the ratio of first to second trawls. For yellow perch there was a strong tendency for the second trawl haul to be less than the first, especially off Warren Dunes. Given the small size of the net, 5.8 m footrope, and normal drift of the boat, the probability is considered low that the observed effect is due to sweeping

the disturbed area on the replicate trawl.

If equal bottom areas could be swept with equal fishing efficiency, variation in the system would be reduced to that of the fish themselves and statistical decision-making power would be improved. Added variance from methodology probably contributed to skewness of the raw-data density function (Fig. A1) as well as leptokurtosis of residuals calculated from log-transformed data. Variation due to replicate trawl hauls sweeping different bottom areas could be eliminated by always trawling a known distance in a fixed time interval, i.e., at a fixed real speed relative to the bottom. This could be accomplished by using radar reflectors on shore or on anchored buoys. It is more difficult to correct for relative fishing efficiencies with and against a current if current speeds vary seasonally and spatially. Efficiency is best averaged by taking replicates in opposite directions.

Given that there now exists 1 yr of data based on 10-min trawls, the value of making the above methodological changes is reduced as there would be no way to accurately relate 1973 data to new data. From the foregoing it shoud be evident that, given the objectives of this study, the trawling procedure in use can give reasonably accurate results whereas single observations or duplicate timed trawl hauls taken in the same direction can give erroneous results, at least in the areas currently under study.

STATISTICAL POWER TO DETECT CHANGES IN FISH POPULATIONS

At this stage in the experiment it is important to evaluate the experimental design to determine if enough samples are being taken to accomplish the primary objective of the study--assessment of environmental impact of Cook Plant thermal discharges. Using the standard deviation (s) from the ANOVAs of trawl catches, it is possible to compute minimal population changes that can be detected when the thermal regime is altered. Yellow perch are used to exemplify the computations.

Least detectable true changes (LDTC) were calculated using a formula derived from Sokal and Rohlf (1969). A least detectable true difference, δ, between two means of transformed data is given by the following equation.

$$\delta = s \quad \frac{2}{n} \; (t_{\alpha[\nu]} + t_{2(1-P)[\nu]})$$

δ = within-cell error standard deviation of an ANOVA comparing preoperational and operational data; this is the square root of the error mean square

n = number of observations in each of the two groups being compared

α = significance level

t = Student's t

ν = degrees of freedom

P = power (the probability that a true difference will be judged significant by the test)

The degrees of freedom, ν, are the same as those for the mean square error term for the factorial ANOVAs used in this study. For any factorial ANOVA, the error degrees of freedom are a function of the number of levels of each of the factors. For example if P, Q, R and S are the factors in an experimental design and p, q, r, and s are their respective numbers of levels, then the error degrees of freedom for that ANOVA are pqrs(n-1), where n is the number of replicates. Thus in our study the number of error degrees of freedom per year will be 56 for the species in group A and 40 for the species in group B:

<u>Group A</u> (alewife, spottails, rainbow smelt)
(2 areas) x (7 months) x (2 depths) x (2 times of day) x (2 replicates - 1) = 56

<u>Group B</u> (yellow perch, trout-perch)
(2 areas) x (5 months) x (2 depths) x (2 times of day) x (2 replicates - 1) = 40

Procedures for an unweighted means analysis of unbalanced data indicate that 1 error degree of freedom must be subtracted for each missing observation. In the 7-month data matrix there were 2 missing observations and in the 5-month data matrix there was 1 missing observation. Consequently there were 54 error degrees of freedom for group A species and 39 for group B species. In calculating the least detectable true differences, however, it was assumed that there were no missing observations. Hence 56 and 40 error degrees of freedom were used in Tables A3-7.

Each of Tables A3-7 consists of two comparisons. The first is a comparison of 1 yr of preoperational abundance indices with 1 yr of operational abundance indices; the second compares 2 preoperational yr with 2 operational yr. Although both Cook Plant and Warren Dunes data were used for estimating the error variance and the degrees of freedom, for purposes of the LDTC calculation only Cook Plant data were considered in making preoperational to operational comparisons of the mean abundance. Thus n, the number of observations in each of the two groups being compared, will be exactly half the number of observations from which the error standard deviation is calculated.

As an illustration of the above, consider the 1973 yellow perch data. The value of s calculated from the 5-month ANOVA was 0.31112 with 39 degrees of freedom. Details of this ANOVA appear in the part of Section B on yellow perch. Again note that 1 degree of freedom was subtracted for a missing observation, giving 39 rather than 40. The number of observations n at the Cook Plant in 1973 was 40. An equal number of observations were made at Warren Dunes, giving a total of 80 for the two areas. Thus on the left side of Table A3 n = 40 is used. Forty error degrees of freedom are

TABLE A3. Least detectable true changes in geometric mean abundance of yellow perch at Cook Plant. These are the values of the ratios 10^{δ}, where δ is the least detectable true change of the transformed variable. It is given as a function of α and P. Two alternatives are included, one with 2 yr of sampling and one with 4 yr of sampling (based on the assumption that the within-cell error standard deviation remains the same as it was in 1973). Each change is expressed as the ratio of the operational value to the pre-operational value of the quantity "mean number per trawl plus one."

	Comparison of 1 pre-operational yr with 1 operational yr; n = 40, ν = 80.		Comparison of 2 pre-operational yr with 2 operational yr; n = 80, ν = 160.	
α/P	.90	.95	.90	.95
.01	1.88	1.99	1.55	1.61
.025	1.77	1.88	1.49	1.55
.05	1.69	1.80	1.44	1.50
.10	1.61	1.71	1.39	1.45

TABLE A4. Least detectable true changes in geometric mean abundance of spottail shiners. See Table A3 for explanation.

	Comparison of 1 pre-operational yr with 1 operational yr; n = 56, ν = 112.		Comparison of 2 pre-operational yr with 2 operational yr; n = 112, ν = 224.	
α/P	.90	.95	.90	.95
.01	1.53	1.59	1.35	1.38
.025	1.47	1.53	1.31	1.35
.05	1.43	1.49	1.28	1.32
.10	1.38	1.43	1.25	1.29

TABLE A5. Least detectable true changes in geometric mean abundance of alewife. See Table A3 for explanation.

	Comparison of 1 pre-operational yr with 1 operational yr; n = 56, ν = 80.		Comparison of 2 pre-operational yr with 2 operational yr; n = 112, ν = 224.	
α/P	.90	.95	.90	.95
.01	1.79	1.90	1.51	1.57
.025	1.70	1.81	1.45	1.51
.05	1.63	1.73	1.41	1.47
.10	1.56	1.65	1.36	1.42

TABLE A6. Least detectable true changes in geometric mean abundance of rainbow smelt. See Table A3 for explanation.

	Comparison of 1 pre-operational yr with 1 operational yr; n = 56, ν = 112.		Comparison of 2 pre-operational yr with 2 operational yr; n = 112, ν = 224.	
α/P	.90	.95	.90	.95
.01	1.62	1.69	1.40	1.44
.025	1.54	1.62	1.36	1.40
.05	1.49	1.56	1.32	1.37
.10	1.44	1.50	1.30	1.33

TABLE A7. Least detectable true changes in geometric mean abundance of trout-perch. See Table A3 for explanation.

	Comparison of 1 pre-operational yr with 1 operational yr; $n = 40$, $\nu = 80$.		Comparison of 2 pre-operational yr with 2 operational yr; $n = 80$, $\nu = 160$.	
α/P	.90	.95	.90	.95
.01	1.86	1.98	1.54	1.60
.025	1.76	1.87	1.48	1.55
.05	1.68	1.78	1.44	1.50
.10	1.60	1.69	1.39	1.45

contributed by each year, giving a total of $\nu = 80$. On the right side of the table, 2 yr of preoperational data are compared to 2 yr of operational data. In each 2-yr period there will be 80 observations at the Cook Plant; hence $n = 80$. As before, 40 degrees of freedom will be contributed to the error standard deviation per year; hence $\nu = 160$. The computation of this last value can be summarized: 2 areas x 5 month x 2 depths x 2 times of day x 4 years x (2 replicates - 1) = 160.

An exactly analogous procedure is used to derive the values of n and ν for the 7-month data matrix used to analyze alewife, spottails and smelt.

To return from the transformed difference δ to the original data, the following derivation is needed. Let f_1 be the true preoperational mean abundance in fish per trawl; its transform is $g_1 = \log(f_1 + 1)$. The operational mean abundance is f_2; its transform is $g_2 = \log(f_2 + 1)$. Let $D = g_2 - g_1$ be the difference between the two transformed quantities. Next, form the ratio of $f_2 + 1$ and $f_1 + 1$ and take its logarithm:

$$\log \frac{f_2 + 1}{f_1 + 1} = \log(f_2 + 1) - \log(f_1 + 1)$$

$$= g_2 = g_1 = D$$

Thus $(f_2 + 1)/(f_1 + 1) = 10^D$. This is an identity that holds no matter how large the change may be. Next, we ask what values the ratio $(f_2 + 1)/(f_1 + 1)$ must assume in order that the transformed quantity D will exceed the least detectable true difference δ. Since the test is two-tailed, the change will be detectable whenever the relation $|D| \geqslant \delta$ holds, that is, whenever $(f_2 + 1)/(f_1 + 1) > 10^{\delta}$ or $< 10^{-\delta}$. Thus the test can detect either an increase or a decrease in the abundance after operation starts.

If one adheres to the 0.01 significance level (δ) as was chosen for 1973 data and sets P = .95, a single year of data after start of thermal

discharges from Cook Plant (1975) should be sufficient to detect approximately a two-fold increase or a 50% decline in relative abundance of yellow perch, expressed as geometric mean number per trawl haul, near the Cook Plant (Table A3). The other four species have LDTCs ranging from 1.59 to 1.98 (Tables A4-7).

When a second year of operational data (1976) is added to the design matrix, LDTCs become even smaller. If variability of the data remains about the same as it was in 1973, the existing experimental design should be able to detect changes as small as a 1.61-fold increase or a 1/1.61-fold decrease in yellow perch abundance near the Cook Plant (α = .01, P = .95, Table A3) or even finer differences if one accepts a lower α and P. Again, all other species considered had smaller LDTCs than yellow perch; the LDTC of 1.38 for spottail shiners is the smallest value estimated for an α = .01 and P = .95 (Table A4).

Such comparisons of Cook Plant operational data will ultimately be made with both Cook Plant preoperational data (the temporal control) and Warren Dunes data (the spatial control). Comparable calculations made with the completed data matrix may give slightly different values for the LDTCs. The LDTCs presented above are considered to be reasonable approximations.

Results of the foregoing analysis are most encouraging and support the contention that the experimental design is adequate, at least, to detect acute impacts of Cook Plant discharges upon fish populations. However, someone or some agency must decide what constitutes a damaging change in a fish species population. There are no quantitative guidelines in the latest draft of proposed guidelines for administration of the 316(a) regulations, which are meant to decide which particular thermal discharges are not harmful to fishes (U. S. Environmental Protection Agency 1974).

Apparently, detected changes in a population will be judged when found, and ultimately a legal precedent will be established. In the meantime, the least detectable true changes computed herein (1.38-1.61) can be judged. If they are determined to be inadequate, the Cook Plant sample program can be either intensified or extended to hopefully meet the desired criteria. However, as noted earlier, intensification is limited by a desire to avoid overfishing and depletion of the fish community being studied.

JUSTIFICATION OF ANOVA FACTORS

The ANOVA factor AREA, which provides the primary spatial control for detecting impacts of Cook Plant heated effluents, was the only factor not entering into significant interactions for all the species considered. AREA had no interactions for yellow perch (Table A8) and main effects related to AREA were insignificant ($P<0.01$) for all species except alewife; this is indicative of the generally small differences between Cook Plant and Warren Dunes. Thus when the Cook Plant begins operation, the factor AREA should provide a reasonably sensitive test of fish population changes in the study areas.

TABLE A8. Comparison of the highest order of significant ($p > 0.01$) interaction between ANOVA factors for the 5 most abundant species in 1973 trawl catches for Cook Plant study areas. Values are based on 4-way ANOVA's, results of which are presented elsewhere in this report.

	ANOVA FACTOR (and highest order of interaction)			
SPECIES	AREA	MONTH	DEPTH	TIME
Spottail	3rd	3rd	3rd	3rd
Alewife	2nd	2nd	2nd	2nd
Smelt	3rd	3rd	3rd	3rd
Yellow perch	none	1st	1st	1st
Trout-perch	2nd	2nd	2nd	2nd

The ANOVA factor MONTH is necessary, as most species were found to make large-scale seasonal migrations in and out of the study areas, and different species of fish utilized the study areas during different months. Likewise the factor DEPTH is necessary; variation in the system from onshore-offshore movements and depth preferences was often considerable, and to ignore differences between samples taken in 6.1 and 9.1-m depths would increase least detectable changes.

The value of the ANOVA factor TIME is best exemplified by trout-perch, a nocturnal species; samples taken only in the day would greatly underestimate trout-perch abundance. Interactions of TIME with other ANOVA factors can result from daily activity cycles of various species and it is useful to consider resulting variation in the system.

The ANOVA factor YEAR, which has only one level, 1973, complete, is needed as it is known that fish populations can undergo large changes from year to year. It is necessary to factor out variation due to natural fish population changes from that which might result from Cook Plant heated effluents. To accomplish the goal of assessing impact of Cook Plant operation, it is imperative to evaluate main effects and interactions for both YEAR and AREA.

GILLNETS

Gillnets are passive fishing gear which are selective for certain species and sizes of fish (Carlander 1953; Heard 1962). Several factors are responsible for bias that analysis of gillnet catches will necessarily entail. Most importantly, two interacting mechanical considerations largely determine a catch: 1) size range of mesh sizes along a particular

net, and 2) morphology of fishes that inhabit an area. Many papers in the literature have dealt with the effect of mesh size on selection of fish. Catch in any particular mesh size is correlated most closely with girth of the fish (Berst 1961; McCombie and Fry 1960). Average sizes of our gilled fish were greater than sizes of fish caught in other gear types used in the study. No YOY of any species were caught in our gillnets. Morphology is another determinant of the catch from gillnets (ctenoid fish, e.g. yellow perch, Bagenal 1972), and heavily toothed species, such as trout, smelt and salmon are particularly susceptible to gillnets due to easier entanglement in the gillnet mesh. Spinous rays on carp and catfish also result in greater catch rate.

Behavioral characteristics are other variables which influence the catch from gillnets. Movement of fish and the associative pattern of grouping of individuals of any species or assemblage of species will determine the quantity of each species caught (Heard 1962; Van Oosten 1935). Our gillnets, 2-m deep, are set on the bottom; thus we might expect a greater abundance of demersal fish in the catch if they are of sufficient size and morphology to be gilled. Species with strong pelagic tendencies such as the alewife will be captured in bottom-set gillnets in numbers which underestimate their actual abundance. Although bottom-set gillnets caught many alewives in our study area, data from Point Beach demonstrated that surface gillnets in shallow areas caught nearly twice as many alewives as did bottom sets (Wis. Elec. Power Co. and Wis. Mich. Power Co. 1973). Catches in gillnets set obliquely surface to bottom in deeper areas off Saugatuck show that the vertical distribution of alewives is highly variable, but that at times the species is rather uniformly distributed at all levels in the water column (unpublished data, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service). Gillnet catches also depend upon fish mobility and the nature of these movements. Mobility is influenced by temperature. During very cold periods most fish move slowly, if at all, and we can infer that an individual fish has a lower probability of being captured when it is relatively immobile. Very high temperatures most likely have a similar diminishing effect with respect to mobility. Standard series gillnets were all set parallel to shore and thus detect more effectively onshore-offshore movements than longshore migrations. The one perpendicular set, station A, did illustrate that longshore movement, especially in salmonids, does occur. Larger fish may move more than smaller ones due to greater foraging requirements, which results in proportionally larger catches (increased selectivity) of these larger fish (Latta 1959). Watt (1956) noted that increased movement as a function of length should be considered in setting up models involving different age classes. Pulling and setting of the nets may overlap peak activity periods of crepuscular fish, e.g. yellow perch (Herman et al. 1969) and spottails (Griswold 1963). Thus any inferences pertaining to day vs. night abundance in the Cook Plant area may be tenuous for certain gillnetted species. Finally, schooling patterns of fish influence gillnet catches; highly contagious distributions result in greater variability of catch data (Moyle and Lound 1960; Bagenal 1972).

From these considerations it is obvious that inferences concerning species composition and their relative size composition would be in serious

error if not supplemented with trawling and seining data. Despite the bias of gillnets, they are valuable indicators of the presence of larger fish in the area. Trawls and seines of the sizes used in this study are notoriously inefficient in the capture of larger fish, particularly salmonids.

Since gillnet sets were not replicated in this study, catch data are not generally amenable to parametric analysis of variance without pooling or using an interaction mean square as the denominator of calculated F values, both of which require assumptions. Bagenal (1972) demonstrated that many replicate gillnet sets are required to obtain reliable mean catches. In his example six gillnet sets would be needed for pike to obtain geometric mean catches with confidence interval limits of the mean times 2 and the mean divided by 2 at the 0.05 α level. Thus in terms of our study, to test for differences between Cook Plant and Warren Dunes we would need to pool day and night gillnet sets and/or 6.1-m and 9.1-m sets to get an estimate of error variance. However, both pooling strategies require the assumption that there are no differences between day and night catches or between 6.1 m and 9.1 m. At the present, such assumptions are unwarranted. If at a future date we decide that pooling is justified, parametric ANOVAs may be included in next year's report.

As a first approximation in our analysis of gillnet data, two non-parametric tests were used to test for differences between areas. Moyle and Lound (1960) concluded that nonparametric tests were of greater value when the number of net sets is small and fish of a particular species are most often taken in the nets. The Mann-Whitney U test for two sample cases and the Kruskal-Wallis test (a further development of the Mann-Whitney tests for K samples) were used. Both tests assume that samples are randomly selected from their respective populations and that each observation in a sample, as well as between samples, is independent (Conover 1971). No tests were made between day and night because day and night codes were not provided for the data matrix. These tests will be included next year.

BEACH SEINES

Beach seines sample the most variable habitat of the inshore regions (the immediate beach zone). Like gillnets there are a number of biases attributable to gear selectivity, but none of these contributes as much to the variability as habitat variability and differential use of the beach zone by the species assemblage in the study areas. Habitat variability encompasses all those factors which affect size of the area swept by the seine. High winds, waves and current alter beach habitat as well as efficiency of beach seines. Resultant shifting of nearshore sand bars due to these effects alters maximum distance from shore which can be effectively sampled by seining. Differing temporal use of the beach zone for spawning and recruitment of larval fish not only illustrates the complex ecology of the beach zone but also introduces "noise" into the data. Although the experimental design was intended for parametric analysis, excessive zeros in the data matrix give high skewness and kurtosis values

to the catch frequency distributions. These distributions violated the normality assumptions of parametric statistics; consequently the Kruskal-Wallis test was used to analyze the data.

PLANKTON NETS

Based on the experiences and advice of L. Wells (personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service), nylon No. 2, 1/2-m diameter plankton nets were used to monitor fish larvae populations in the Cook Plant study area. Ease of handling and catch efficiency were the major criteria in selecting the 1/2-m diameter net. A larger diameter net would be too long and cumbersome for both the beach zone and for use from the R/V MYSIS. Smaller nets filter less water and thus are undesirable. Efficiency of a plankton net (percent of the water that passes through the net) is a function mainly of its mesh size. Size of larval catches depends on current velocity, planktonic concentrations and behavior characteristics of fish larvae. The No. 2 net has 351 micron openings (0.351 mm) which should prevent most larvae and eggs from escaping. Spottail shiner eggs (0.6 to 1.0-mm diameter) were the smallest eggs observed for any species common to the study area, thus the No. 2 net should be adequate. Decreasing mesh size poses problems of clogging. A No. 5 net, used in our 1972 sampling, often clogged with algae preventing filtering of water. Similarly, a large algal bloom in October 1973 resulted in net clogging in our No. 2 net. Should this problem worsen, a larger mesh size may be required.

Differing behavior characteristics of fish species in the inshore zone cause bias in plankton net catches. Numbers of demersal species such as spottails, sculpin and trout-perch were probably grossly underestimated in 1973. Extensive sled tow sampling was performed in 1974 to overcome this discrepancy. Another confounding factor concerns diel differences in numerical abundance. We have found that at least two species, smelt and alewife, exhibited diel vertical and possibly horizontal migrational patterns. Thus day sampling, when larval smelt are in the lower strata, would greatly underestimate their abundance.

As fish length increases, avoidance reactions to the plankton net increases (gear efficiency varies inversely as fish mature). Few fish are caught beyond a certain species' specific critical length. For species whose spawning periods are short (e.g. smelt), this poses no problem, since most of the larvae will be within a certain size range, then when smelt larvae are no longer caught one can conclude that the species' critical length has been reached by that year class of smelt, beyond which they are seldom caught in plankton nets. However, for species whose spawning period is more than a month (e.g. alewife) there are problems associated with varying size classes, and possibly an underestimation of total numbers of fish larvae results. This occurs because the net is only sampling the newly hatched and smaller of the total population of alewife larvae present. Interpretation problems then follow. Net avoidance results in an interim length interval where alewives are large enough to avoid plankton nets yet too small to be captured by other gear types.

Extensive sampling was also performed in the beach zone (0-2 m) in 1973. This highly variable habitat has not been sampled adequately in the past, and knowledge of its usage by fish larvae may prove valuable when plant operation commences. Strong current effects are particularly pronounced in the beach zone where results of strong winds are eventually felt.

As volume of water sampled is a function of both current and velocity of the net in the water, we chose to do two larvae tows in opposite directions in 1973 to average gear efficiency effects due to current. In 1974 approximate current velocity was determined using a drift bottle and simultaneous duplicate tows were made against the current, permitting us to control effects due to current over the sampling season. This is in contrast to trawling methodology where current is not known and replicates are taken in opposite directions.

Fish larvae samples were not replicated on the R/V MYSIS due to time and cost constraints. Limited statistical testing can be performed by pooling depths, and sometimes stations, to determine various treatment effects. Seasonal abundance changes of fish larvae necessitated deletion of months when few or no larvae were present for accurate statistical testing. Finally, flowmeter methodology presented numerous problems but proved invaluable in quantification of numbers. The large range and high variability in flowmeter readings (12-1900) in these 5-min tows necessitates use of the flowmeter for standardizing tow volumes. Alternative methods of measuring volume sampled require sophisticated and costly equipment. Whereas if one is willing to accept upper level contamination by fish larvae in tows performed at lower depths (a problem easily corrected by calculation), a reliable, consistent and repeatable result can be obtained.

SECTION B

SPATIAL AND TEMPORAL DISTRIBUTION, GONAD CONDITION AND TEMPERATURE-CATCH RELATIONSHIPS OF ADULT AND JUVENILE FISHES

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INTRODUCTION

Our first step in monitoring the biology of fishes in Lake Michigan was establishment of appropriate sampling stations in the vicinity of the Cook Plant and at the reference location Warren Dunes. To establish a data base-line during the preoperational period, selected station fishing data were designated as the standard series, other netting was termed supplementary, and when all fishing activities were combined this was called total fishing efforts or total samples. These stations were established to determine the spatial and temporal distribution of fish populations in the vicinity of the Cook Plant. From 1973 on, the stations will be sampled extensively in an attempt to detect any changes in the numbers and species of the resident and migratory populations.

The objective of this section is to provide data to which postoperational data can be compared. It includes a discussion and elaboration of the biology of each species established from our data and literature reviews conducted to date. The section utilizes results and statistical tests discussed in Section A.

Our results are organized into four major parts. The first part discusses the number of species we captured and compares this with other species lists from nearby areas. It also attempts to depict the broader aspects of fish movement, distribution and occurrence in the inshore zone of Lake Michigan, with emphasis on species complexes. The second part is an elaboration of what species are and are not caught by our various gear, and points out that because of the great selectivity of these various nets, different net types are needed to delineate species assemblages.

The last two parts concern individual fish species. First is a detailed discussion of the five most abundantly caught species. Included are statistical analyses of the seasonal, spatial and diel distribution, length-frequency histograms, temperature-catch relationships from field-caught fish, gonad development data, spawning times and some comments on disease. The last part discusses briefly the remaining less abundant species, including sizes of fish caught, seasonal, spatial and diel behavior patterns, gonad development and spawning times if possible, and any diseases noted.

We have attempted to characterize the "normal" distribution, behavior and abundance of fish populations in the area as well as to note any abnormalities, such as diseases in fish or aberations, natural or unnatural, in station catches, so that our ability to detect possible differences in the postoperational phase will be maximized. Such future sampling will help clarify just how fruitful our efforts in the preoperational phase have been.

METHODS

LOCATION OF SAMPLING STATIONS

Seven permanent sampling stations were established in Lake Michigan off the Cook Plant (experimental area) and off Warren Dunes State Park (control area) (Fig. B1). Routine samples taken at these stations are referred to in this report as the standard series. At the Cook Plant there were two beach seining stations (A, B), one north and one south of the plant, and two offshore stations (C, D) at 6.1-m (20 ft) and 9.1-m (30 ft) depths where trawl and gillnet samples were taken. At Warren Dunes there were one beach seining station (F) and two offshore stations (G, H) at 6.1-m and 9.1-m depths for trawl and gillnet samples. Offshore stations at 6.1-m (C, G) and 9.1-m (D, H) were established to correspond to location of the Cook Plant's three intake structures, 671 m (2200 ft) offshore in 9.1 m of water and the two discharge structures 354 m (1160 ft) offshore in 6.1 m of water.

Although the standard series had priority, occasionally there was time to take supplementary trawl or gillnet samples at the standard stations or at other stations (E, M, L; Fig. B1) established for this purpose. All methods used at supplementary stations were identical to those used at standard series stations except the setting of gillnets perpendicular to shore at station A in 1.5-3.0 m (5-10 ft) of water.

Substrate at seining stations A and F during 1973 was sand with some gravel, which is typical of beaches in southeastern Lake Michigan. Distinct sand bars parallel to shore were present during most sampling months. Station B, just south of Cook Plant, differed from the other two seining stations in lacking a well-developed sand bar; the bottom was flat and shallow for a considerable distance due to the sand replenishment program south of the safe harbor which had been carried on by the company. Fish catches at station B reflected this difference.

Substrate at all offshore stations--C, D, G. H--was sandy with coarser sands at Warren Dunes (see Seibel and Ayers 1974 for a detailed discussion of substrates in the area). Slope of the bottom off Cook Plant was steeper than off Warren Dunes, thus trawl and gillnet samples from Warren Dunes were taken further offshore.

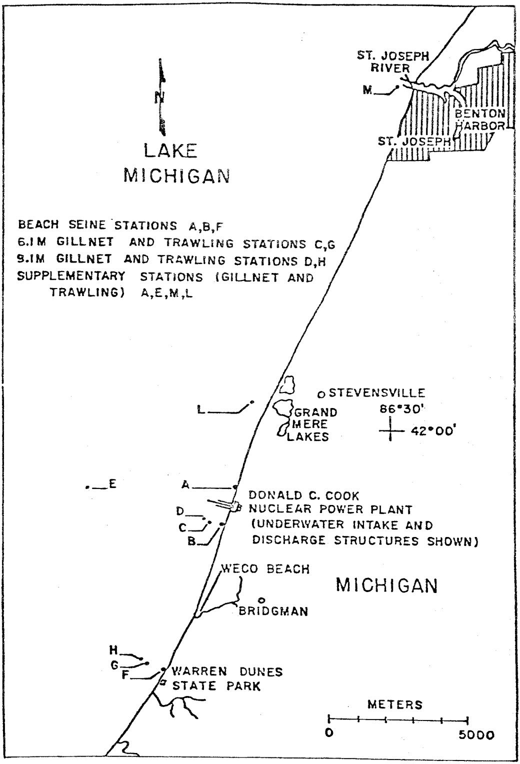


FIG. B1. Map of the Cook Plant and Warren Dunes study areas in southeastern Lake Michigan 1973; only schemata of underwater structures are shown.

GEAR

Duplicate 10-min bottom tows were taken monthly both day and night at the four offshore stations (C, D, G, H), using a semi-balloon, nylon trawl having a 4.9-m (16 ft) headrope and a 5.8-m (19 ft) footrope. The body and cod end of the net were composed respectively of 3.8-cm (1.5 in) and 3.2-cm (1.25 in) stretch mesh, while the cod end interliner was 1.27-cm (0.5 in) stretch mesh. All trawl hauls were made at an average speed of 4.8 km/hr (3 mph), i.e., at a fixed rpm using the University of Michigan's R/V MYSIS. The trawl was towed parallel to shore following 6.1-m and 9.1-m depth contours; one replicate was taken from south to north and the other north to south.

Nylon experimental gillnets 160.1 m x 1.8 m (525 ft x 6 ft) were set at the offshore stations (C, D, G, H) at least once per month for about 12 hr during daylight and 12 hr during the night. Nets were composed of 12 panels of netting as follows: 7.6-m (25 ft) sections of each of the following mesh sizes (bar measure)--1.3 cm (0.5 in), 1.9 cm (0.75 in) and 2.5 cm (1.0 in); 15.3-m (50 ft) sections of mesh sizes 3.2-7.6 cm (1.25-3.0 in) by 0.3-cm (0.25 in) intervals; and a final 15.3-m section of 10-cm (4 in) mesh. All gillnets were set parallel to shore on the bottom, except supplementary sets at station A which were set perpendicular to shore.

Beach seining was conducted during periods of reduced wave height and current using a nylon seine 38.0 m x 1.8 m (125 ft x 6 ft) with a 9.1-m (30 ft) bag; the entire seine had 0.5-cm (0.25 in) bar mesh. The seine was first stretched perpendicular to the shoreline and then pulled parallel to shore a distance of 61 m (200 ft). Duplicate, non-overlapping samples were taken in this manner both day and night once each month at seining stations (A, B, F). The seine was pulled against the current or southerly when no current was detectable. When the current was too strong to seine against, seining was done with the current.

MISSING SAMPLES

In summary, the standard monthly sample series consisted of 16 trawl hauls, 8 gillnet sets and 12 beach seine hauls. While it was hoped that standard series fishing could be performed every month of the year, this was not always possible due to equipment failure, inclement weather and ice. Following is a summary of samples missing from the standard series in 1973 (missing observations in parentheses):

1. January - all trawls (16), gillnets (8), seines (12)
2. February - all trawls (16), day and night gillnet sets at G and H, day gillnet sets at C and D (6), night seines at A, B, F, day seines at F (8).
3. March - all trawls (16), day seine at B (1) day and night seines at F (4)
4. April - day trawl at G (1)

5. July - day seine at F (1)
6. September - night trawl at G (1)
7. November - all trawls (16), night gillnet sets at G and H (2), night seines at F (2)
8. December - all trawls (16), all gillnets except night gillnet at C (7), all seining (12)

PHYSICAL AND LIMNOLOGICAL DATA

Each time a particular fishing gear was used at a station, weather and other physical parameters were recorded (Tables B1-4). Wind direction and speed were obtained using an anemometer when aboard the R/V MYSIS and estimated at other times. Wave direction and height were estimated visually. Water temperatures for trawl, gillnet and seine samples were taken at the surface and fishing depth using a battery-operated telethermometer. A glass mercury thermometer was sometimes used during beach seining. Current at beach stations was estimated by measuring the time it took a neutrally buoyant object to travel 3.1 m (10 ft). Secchi disc readings were taken during daytime each time a fishing gear was used.

LABORATORY ANALYSIS OF FISH

Fish from seines, gillnets and trawls were processed fresh when time permitted, and otherwise put in plastic bags and frozen at the Cook Plant as soon as possible (usually within 2 hr) and stored in freezers. Trawl catches were frozen immediately on board the R/V MYSIS. At the laboratory, bags of fish were thawed as needed, separated by species, then grouped according to size classes. When large numbers of a particular size class were present, a subsample was randomly selected and a mass weight of the remaining group taken. Total length (to nearest mm, fin pinched), weight (to nearest 0.1 g using a P1000 Mettler balance), sex, gonad condition, fin clips, lamprey scars, evidence of disease and parasites were recorded for all fish except those mass weighed. Large fish and fish in mass weights (>1000 g) were weighed with a hanging scale spring balance (K023G Chatillon) to the nearest 25 g.

Gonad condition was described according to five stages of development: 1) underdeveloped, 2) moderately developed--for females, eggs discernible but not fully ripe, 3) ripe, 4) ripe-running--sex products exiting with application of moderate pressure, 5) spent. Other categories included: 6) fish decomposed or mutilated (traveling screen catches at times) so that sex was impossible to determine, 7) unable to ascertain sex on an adult fish, 8) immature. Scale samples were also taken from selected species (alewife, rainbow smelt, perch, coho, chinook, lake trout) but have not yet been analyzed.

All fish were identified to species using Hubbs and Lagler (1964), Trautman (1957) and Eddy (1957), when necessary with the exception of the genera *Coregonus* (subgenus *Leucichthys*) and *Cottus*. Satisfactory keys for

TABLE B1. Date and length of time trawling gear was used, as well as some physical and limnological parameters measured at the time of fish collection.

Starting date	Time		Station	Temperature C		Wind		Waves		Weather	Secchi disc (m)
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)		
4-26-73	1045	1057	C	7.2	7.2	NE	10-15	N	.4	Fair	-
4-26-73	1110	1120	C	7.2	7.2	NE	10-15	N	.4	Fair	-
4-29-74	0035	0045	C	6.4	6.2	E	5-10	N	.3-.6	Fair	-
4-29-73	0050	0100	C	6.4	6.2	E	5-10	N	.3-.6	Fair	-
4-26-73	0831	0841	D	7.0	7.2	NE	0-5	N	.4	Overcast	-
4-26-73	0851	0901	D	7.0	7.2	NE	0-5	N	.4	Overcast	-
4-28-73	2325	2335	D	7.0	7.0	N	0-5	N	.7	Fair	-
4-28-73	2340	2350	D	7.0	7.0	N	0-5	N	.7	Fair	-
4-26-73	1450	1505	G	7.2	7.6	N	15-20	N	.6-.9	Fair	1.8
4-26-73	1545	1555	G	7.2	7.6	N	15-20	N	.6-.9	Fair	1.8
4-28-73	2155	2205	G	7.7	7.5	-	-	-	-	Fair	-
4-28-73	2212	2222	G	7.7	7.5	-	-	-	-	Fair	-
4-26-73	1320	1330	H	7.4	6.8	N	10-15	N	.4-.6	Fair	2.2
4-26-73	1345	1355	H	7.4	6.8	N	10-15	N	.4-.6	Fair	2.2
4-28-73	2045	2055	H	7.4	7.0	NE	0-5	N	.6- 1	Fair	-
4-28-73	2105	2115	H	7.4	7.0	NE	0-5	N	.6-.1	Fair	-
5-15-73	1650	1700	C	11.8	10.7	W	0-5	W	.2	Fair	3.1
5-15-73	1705	1715	C	11.8	10.7	W	0-5	W	.2	Fair	3.1
5-15-73	2028	2038	C	11.9	10.7	SW	5-10	-	-	Pt. Cloudy	-
5-15-73	2050	2100	C	11.9	10.7	SW	5-10	-	-	Pt. Cloudy	-
5-15-73	1535	1545	D	11.3	10.1	W	0-5	W	.3-.6	Fair	2.9
5-15-73	1555	1605	D	11.3	10.1	W	0-5	W	.3-.6	Fair	2.9
5-15-73	2138	2148	D	10.3	9.3	SW	5-10	S	.3	Pt. Cloudy	-
5-15-73	2157	2207	D	10.3	9.3	S	10-15	S	.3	Pt. Cloudy	-
5-14-73	2158	2208	G	10.2	10.2	NW	0-5	NW	.3	Fair	-
5-14-73	2220	2230	G	10.2	10.2	NW	0-5	NW	.3	Fair	-
5-15-73	1412	1422	G	10.8	10.2	NW	0-5	W	.6	Fair	2.6
5-15-73	1425	1435	G	10.8	10.2	NW	0-5	W	.6	Fair	2.6
5-14-73	2040	2050	H	9.9	9.4	NW	0-5	NW	.3	Fair	-
5-14-73	2100	2110	H	9.9	9.4	NW	0-5	NW	.3	Fair	-

TABLE B1 continued.

Starting date	Time		Station	Temperature C		Wind		Waves		Weather	Secchi disc (m)
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)		
5-15-73	1247	1257	H	10.8	10.1	W	0-5	SW	.3-.6	Fair	3.6
5-15-73	1310	1320	H	10.8	10.1	W	0-5	SW	.3-.6	Fair	3.6
6-19-73	1254	1304	C	22.0	21.0	S	5-10	S	.5	Cloudy	3.0
6-19-73	1311	1321	C	22.0	21.0	S	5-10	S	.5	Cloudy	3.0
6-19-73	2147	2157	C	20.8	20.8	SW	0-5	-	0-.2	Pt. Cloudy	-
6-19-73	2211	2221	C	20.8	20.8	SW	0-5	-	0-.2	Pt. Cloudy	-
6-19-73	1056	1106	D	21.2	18.5	S	5-10	S	.3	Pt. Cloudy	3.5
6-19-73	1115	1125	D	21.2	18.5	S	5-10	S	.3	Pt. Coudy	3.5
6-19-73	2035	2045	D	21.5	16.5	Calm		S	0-.2	Haze	-
6-19-73	2053	2103	D	21.5	16.5	Calm		S	0-.2	Haze	-
6-18-73	1652	1702	G	21.3	19.0	S	0-5	S	.2	Pt. Cloudy	2.5
6-18-73	1712	1722	G	21.3	19.0	S	0-5	S	.2	Pt. Cloudy	2.5
6-18-73	2140	2150	G	20.5	19.2	SE	10-15	S	.2	Overcast	2.5
6-18-73	2158	2208	G	20.5	19.2	SE	10-15	S	.2	Overcast	2.5
6-18-73	1437	1447	H	20.2	18.5	S	0-5	S	.2	Pt. Cloudy	3.0
6-18-73	1459	1509	H	20.2	18.5	S	0-5	S	.2	Pt. Cloudy	3.0
6-18-73	2027	2037	H	21.5	16.3	SE	10-15	S	.2	Overcast	2.5
6-18-73	2046	2056	H	21.5	16.3	SE	10-15	S	.2	Overcast	2.5
7-17-73	1127	1137	C	22.0	21.2	SE	5-10	SE	.2	Fair	-
7-17-73	1147	1157	C	22.0	21.2	SE	5-10	SE	.2	Fair	-
7-17-73	2014	2024	C	22.6	22.4	NE	0-5	Calm		Fair	-
7-17-73	2032	2042	C	22.6	22.4	NE	0-5	Calm		Fair	-
7-17-73	1016	1026	D	21.1	18.2	SE	5-10	SE	.2	Fair	-
7-17-73	1035	1045	D	21.1	18.2	SE	5-10	SE	.2	Fair	-
7-17-73	2129	2139	D	21.5	15.5	SE	5-10	Calm		Fair	-
7-17-73	2148	2158	D	21.5	15.5	SE	5-10	Calm		Fair	-
7-16-73	1528	1538	G	22.2	22.2	NW	15-20	NW	.6	Fair	3.0
7-16-73	1549	1559	G	22.2	22.2	NW	15-20	NW	.6	Fair	3.0
7-16-73	2006	2016	G	22.6	19.6	NE	10-15	NW	.3	Fair	-
7-16-73	2026	2036	G	22.6	19.6	NE	10-15	NW	.3	Fair	-
7-16-73	1417	1427	H	22.5	22.0	N	10-15	NW	.6	Fair	3.5
7-16-73	1440	1450	H	22.5	22.0	N	10-15	NW	.6	Fair	3.5
7-16-73	2120	2130	H	21.8	18.2	NE	5-10	NW	.3	Fair	-
7-16-73	2141	2151	H	21.8	18.2	NE	5-10	NW	.3	Fair	-

TABLE B1 continued.

Starting date	Time Start	Time Finish	Station	Temperature C Surface	Temperature C Fish depth	Wind Dir from	Wind Speed mph	Waves Dir from	Waves Ht (m)	Weather	Secchi disc (m)
8-22-73	1140	1150	C	11.3	9.2	S	5-10	E	.1	Pt. Cloudy	0.6
8-22-73	1156	1206	C	11.3	9.2	S	5-10	E	.1	Pt. Cloudy	0.6
8-21-73	2240	2250	C	14.3	12.2	NE	0-5	NW	.6	Pt. Cloudy	-
8-21-73	2258	2308	C	14.3	12.2	NE	0-5	NW	.6	Pt. Cloudy	-
8-21-73	2148	2158	D	11.3	8.5	NE	0-5	N	1.0	Pt. Cloudy	-
8-21-73	2129	2139	D	11.3	8.5	NE	0-5	N	1.0	Pt. Cloudy	-
8-22-73	1016	1026	D	11.3	8.5	E	0-5	E	.1	Pt. Cloudy	0.7
8-22-73	1039	1049	D	11.3	8.5	E	0-5	E	.1	Pt. Cloudy	0.7
8-22-73	1549	1559	G	16.5	12.4	N	0-5	NW	.1	Pt. Cloudy	1.3
8-22-73	1607	1617	G	16.5	12.4	N	0-5	NW	.1	Pt. Cloudy	1.3
8-22-73	2004	2014	G	16.3	14.9	SE	5-10	Calm		Cloudy	-
8-22-73	2023	2033	G	16.3	14.9	SE	5-10	Calm		Cloudy	-
8-22-73	1437	1447	H	17.1	12.9	Calm		Calm		Fair	1.1
8-22-73	1458	1508	H	17.1	12.9	Calm		Calm		Fair	1.1
8-22-73	2115	2125	H	17.0	15.8	SE	5-10	Calm		Fair	-
8-22-73	2134	2144	H	17.0	15.8	SE	5-10	Calm		Fair	-
9-18-73	1232	1242	C	13.0	12.0	S	0-5	W	.3	Fair	2.5
9-18-73	1256	1306	C	13.0	12.0	S	0-5	W	.3	Fair	2.5
9-20-73	2039	2049	C	14.3	14.1	NE	10-15	N	.6	Fair	-
9-20-73	2023	2033	C	14.3	14.1	NE	10-15	N	.6	Fair	-
9-18-73	1011	1021	D	12.5	9.0	SE	0-5	W	.3-.5	Pt. Cloudy	2.5
9-18-73	1031	1041	D	12.5	9.0	SE	0-5	W	.3-.5	Pt. Cloudy	2.5
9-20-73	1922	1932	D	18.7	14.4	NE	10-15	N	.6	Fair	-
9-20-73	1942	1952	D	18.7	14.4	NE	10-15	N	.6	Fair	-
9-17-73	1552	1602	G	11.5	11.0	SW	10-15	SW	.5	Overcast	2.0
9-17-73	1609	1619	G	11.5	11.0	SW	10-15	W	.5	Overcast	2.0
9-18-73	2057	2102	G	14.1	14.5	Calm		Calm		Fair	-
9-18-73	2115	2125	G	14.1	14.5	Calm		Calm		Fair	-
9-17-73	1438	1448	H	12.2	10.0	SW	5-10	SW	.3	Overcast	2.0
9-17-73	1458	1508	H	12.2	10.0	SW	5-10	SW	.3	Overcast	2.0
9-18-73	1941	1951	H	14.5	14.8	Calm		Calm		Fair	-
9-18-73	2002	2012	H	14.5	14.9	Calm		Calm		Fair	-
10-27-73	0928	0938	C	13.7	13.7	SE	10-15	SE	.3	Cloudy	-

TABLE B1 continued.

Starting date	Time		Station	Temperature C		Wind		Waves		Weather	Secchi disc (m)
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)		
10-27-73	0946	0956	C	13.7	13.7	SE	10-15	SE	.3	Fair	2.2
10-26-73	2237	2247	C	13.8	13.5	SE	0-5	NW	.3	Fair	-
10-26-73	2255	2305	C	13.8	13.5	SE	0-5	NW	.3	Fair	-
10-26-73	1600	1610	D	14.9	15.7	NW	0-5	NW	.3	Fair	3.0
10-26-73	1623	1633	D	14.9	15.7	NW	0-5	NW	.3	Fair	3.0
10-26-73	2125	2135	D	13.9	13.9	SE	0-5	-	-	Pt. Cloudy	-
10-26-73	2145	2155	D	13.9	13.9	SE	0-5	-	-	Pt. Cloudy	-
10-26-73	1425	1435	G	15.1	15.1	NW	5-10	NW	.5	Fair	2.3
10-26-73	1442	1452	G	15.1	15.1	NW	5-10	NW	.5	Fair	2.3
10-26-73	1950	2000	G	14.2	14.5	SE	0-5	NW	.6	Fair	-
10-26-73	2005	2015	G	14.2	14.5	SE	0-5	NW	.6	Fair	-
10-26-73	1309	1319	H	14.9	14.3	NW	10	NW	.5	Fair	3.8
10-26-73	1330	1340	H	14.9	14.3	NW	10	NW	.5	Fair	3.8
10-26-73	1910	1920	H	14.6	14.3	SE	0-5	NW	.3	Fair	-
10-26-73	1928	1938	H	14.6	14.3	SE	0-5	NW	.3	Fair	-

TABLE B2. Date and length of time gillnets were used, as well as some physical and limnological parameters measured at the time of fish collection.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
2-06-73	1630	0730	C	1.7	1.7	SE	10-15	SE	.6	Rain
2-06-73	1630	0730	D	1.7	1.7	SE	10-15	SE	.6	Rain
3-27-73	1450	1845	C	5.1	4.2	N	0-5	N	.3	Fair
3-27-73	1850	0925	C	5.1	4.2	N	0-5	N	.3	Fair
3-27-73	1450	1825	D	4.8	4.0	N	0-5	N	.3	Fair
3-27-73	1835	0945	D	4.8	4.0	N	0-5	N	.3	Fair
3-27-73	1402	1740	G	5.5	4.8	N	0-5	N	.3	Fair
3-27-73	1750	1120	G	5.5	4.8	N	0-5	N	.3-.4	Fair
3-27-73	1402	1710	H	5.5	4.2	N	0-5	N	.3	Fair
3-27-73	1720	1110	H	5.5	4.8	N	0-5	N	.3-.4	Fair
4-13-73	1015	2010	C	5.5	5.0	N	5-10	NW	.3-.6	Fair
4-13-73	2100	0805	C	5.0	5.1	var	0-5	NW	.3-.6	Fair
4-13-73	1030	2030	D	6.0	5.1	N	5-10	NW	.3-.6	Fair
4-13-73	2040	0755	D	5.1	5.1	var	0-5	NW	.3-.6	Fair
4-19-73	0840	1700	G	7.9	7.8	E	10-15	Calm		Pt. Cloudy
4-18-73	2140	0745	G	7.0	7.0	SE	5-10	Calm		Overcast
4-19-73	0900	1645	H	7.5	7.4	E	10-15	Calm		Pt. Cloudy
4-18-73	2125	0800	H	7.4	6.8	SE	5-10	Calm		Overcast
5-17-73	0820	1900	C	12.0	10.1	SW	10-15	SW	.6-1	Pt. Cloudy
5-18-73	2135	0720	C	11.0	10.0	SE	5-15	S	.2	Fair
5-18-73	2120	0700	D	11.0	10.0	SE	10-15	S	.2	Fair
5-17-73	0800	1845	D	10.0	10.0	SW	10-15	SW	.6-1	Pt. Cloudy
5-17-73	0800	1650	G	10.9	10.0	Calm		Calm		Overcast
5-17-73	2225	0750	G	10.5	9.5	SE	0-5	Calm		Fair
5-17-73	0730	1630	H	11.0	10.0	Calm		Calm		Overcast
5-17-73	2205	0700	H	10.5	9.5	SE	0-5	Calm		Fair
6-18-73	0835	1930	C	17.9	18.6	Calm		Calm		Overcast
6-17-73	2040	0745	C	20.5	18.5	SW	0-5	SW	.2	Haze
6-18-73	0815	1915	D	19.5	18.0	SE	0-5	Calm		Haze
6-17-73	2030	0730	D	21.5	18.5	SW	0-5	SW	.2	Haze
6-20-73	0910	1830	G	16.9	16.5	SW	-	SW	.3	Fair

TABLE B2 continued.

Starting Date	Time Start	Time Finish	Station	Temperature C Surface	Temperature C Fish depth	Wind Dir from	Wind Speed mph	Waves Dir from	Waves Ht (m)	Weather
6-18-73	2100	0740	G	19.5	19.0	S	0-5	S	.2	Pt. Cloudy
6-18-73	2004	0755	H	19.0	17.5	S	10-15	S	.2	Pt. Cloudy
6-20-73	0920	1830	H	17.9	16.7	SW	-	SW	.3	Fair
7-16-73	0800	1755	C	22.6	19.9	NW	10-15	NW	.6-1	Fair
7-17-73	2150	0530	C	20.3	11.9	SE	5-10	SE	.2	Pt. Cloudy
7-16-73	0900	1910	D	20.2[1]	19.9	NW	10-15	NW	.6-1	Pt. Cloudy
7-18-73	0925	1715	D	21.2	19.5	SE	-	Calm		Pt. Cloudy
7-17-73	0930	2045	G	20.0	15.4	SE	10-15	SE	.2	Pt. Cloudy
7-17-73	2200	0550	G	22.7	13.9	var	5-10	NW	.2	Pt. Cloudy
7-17-73	0945	2000	H	20.0	15.0	SE	10-15	SE	.2	Pt. Cloudy
7-17-73	2145	0530	H	22.7	13.9	var	var	NW	.2	Fair
8-23-73	0810	1850	C	16.2	14.4	E	0-5	Calm		Rain
8-21-73	2030	0543	C	11.0	9.0	NE	5-10	NW	.1	Fair
8-09-73	2130	0320	D	23.5	23.5	SE	5-15	SW	.4	Rain
8-23-73	0750	1904	D	16.2	14.5	E	0-5	Calm		Cloudy
8-21-73	2005	0530	D	11.5	8.5	NE	5-10	NW	.1	Fair
8-22-73	2215	0610	G	15.5	15.0	SE	0-5	Calm		Fair
8-22-73	0840	2030	G	11.5	9.0	E	0-5	NW	.3	Fair
8-22-73	0830	2010	H	11.0	8.0	NE	0-5	NE	.1	Fair
8-22-73	2145	0630	H	15.5	14.0	NR	NR	NR	NR	Fair
9-17-73	0820	1700	C	12.7	11.5	SE	10-15	SE	.6-1	Rain
9-18-73	2110	0700	C	14.5	13.5	Calm		NW	.3	Fair
9-17-73	0830	1630	D	12.7	11.5	SE	15-20	SE	.6-1.0	Rain
9-18-74	2050	0700	D	14.4	14.5	Calm		NW	.3	Fair
9-18-73	2008	0720	G	14.6	15.0	Calm		NW	.3	Fair
9-21-73	0826	1800	G	13.0	12.7	NR	NR	NR	NR	Pt. Cloudy
9-18-73	1950	0630	H	15.0	15.0	Calm		NW	.3	Fair
9-21-73	0812	1750	H	13.4	12.6	SE	5-10	SE	.1	Pt. Cloudy
10-22-73	1000	1730	C	13.0	13.1	SE	5-10	SE	.1	Fair
10-22-73	2040	0600	C	14.0	14.0	SE	5-10	SE	.1	Fair
10-22-73	1005	1745	D	10.9	10.6	SE	5-10	SE	.1	Fair

TABLE B2 continued.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
10-22-73	2010	0615	D	14.2	14.0	SE	5-10	SE	.1	Fair
10-22-73	1040	1825	G	13.9	13.8	SE	5-10	SE	.1	Fair
10-22-73	1835	0655	G	13.4	13.5	SE	5-10	SE	.1	Fair
10-22-73	1025	1810	H	14.0	13.9	SE	5-10	SE	.1	Fair
10-22-73	1815	0715	H	13.3	13.8	SE	5-10	SE	.1	Fair
11-14-73	1420	1825	A	10.0	9.3	Calm		W	.1	Overcast
11-14-73	2010	2240	C	10.0	9.3	SE	10-15	SE	.3	Overcast
11-14-73	1427	1842	D	10.0	9.3	Calm		W	.1	Overcast
11-14-73	1950	2250	D	10.0	9.3	SE	10-15	SE	.3	Overcast
11-14-73	1503	1705	G	10.0	10.0	S	0-5	SW	.1	Overcast
11-14-73	1510	1742	H	10.0	10.0	S	0-5	SW	.1	Overcast
12-17-73	2300	1030	C	2.0	2.5	SE	0-5	NW	.3	Overcast

[1]Upwelling occurred when set.

TABLE B3. Date and length of time seines were used, as well as some physical and limnological parameters measured at the time of fish collection.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
2-02-73	1315	1324	A	3.5	3.0	S	5-10	W	0.3	Overcast
2-02-73	1328	1338	A	3.5	3.0	S	5-10	W	0.3	Overcast
2-02-73	1428	1437	B	5.2	4.2	S	5-10	SW	.3-.6	Overcast
2-02-73	1447	1500	B	5.2	4.2	S	5-10	SW	.3-.6	Overcast
3-16-73	1315	1330	A	8.0	8.0	NW	15-20	NW	.3	Overcast
3-16-73	1330	1345	A	8.0	8.0	NW	15-20	NW	.3	Overcast
3-15-73	2225	2235	A	8.0	8.0	var	0-5	W	.3-.6	Cloudy
3-15-73	2245	2255	A	8.0	8.0	var	0-5	W	.3-.6	Cloudy
3-16-73	1400	1410	B	8.0	8.0	NW	15-20	NW	.3	Overcast
3-14-73	2235	2245	B	10	10	S	15-20	SW	.6	Fair
3-14-73	2245	2300	B	10	10	S	15-20	SW	.6	Fair
4-13-73	1420	1428	A	7.5	7.5	NW	0-5	NW	.3-.5	Fair
4-13-73	1435	1440	A	7.5	7.5	NW	0-5	NW	.3-.5	Fair
4-18-73	2345	2350	A	9.7	9.7	SE	0-5	Calm		Overcast
4-18-73	0005	0010	A	9.7	9.7	SE	0-5	Calm		Overcast
4-13-73	1515	1522	B	8.1	8.1	NW	0-5	W	.3	Fair
4-13-73	1528	1535	B	8.1	8.1	NW	0-5	W	.3	Fair
4-19-73	0047	0051	B	10.2	9.9	SE	0-5	Calm		Overcast
4-18-73	0100	0105	B	10.2	9.9	SE	0-5	Calm		Overcast
4-13-73	1735	1745	F	8.8	8.8	var	0-5	NW	.3	Fair
4-13-73	1748	1755	F	8.8	8.8	var	0-5	NW	.3	Fair
4-18-73	2153	2158	F	9.5	9.5	SE	0-5	Calm		Overcast
4-18-73	2205	2210	F	9.5	9.5	SE	0-5	Calm		Overcast
5-17-73	2248	2253	A	11.8	11.5	Calm		Calm		Fair
5-17-73	2300	2307	A	11.8	11.5	Calm		Calm		Fair
5-18-73	1425	1430	A	12.5	12.5	SW	0-5	SW	.1	Overcast
5-17-73	2220	2223	B	10.7	10.7	Calm		Calm		Fair
5-17-73	2227	2232	B	10.7	10.7	Calm		Calm		Fair
5-18-73	1520	1530	B	12.5	11.6	Calm		Calm		Overcast
5-18-73	1550	1555	B	12.5	11.6	Calm		Calm		Overcast
5-18-73	1700	1705	F	12.1	12.1	Calm		Calm		Overcast
5-18-73	1710	1715	F	12.1	12.1	Calm		Calm		Overcast

TABLE B3 continued.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
5-18-73	2245	2247	F	11.9	11.9	SE	5-15	SE	.2	Cloudy
5-18-73	2250	2260	F	11.9	11.9	SE	5-15	SE	.2	Cloudy
6-19-73	1615	1620	A	23.5	23.0	SW	0-5	SW	.3	Pt. Cloudy
6-19-73	1625	1630	A	23.5	23.0	SW	0-5	SW	.3	Pt. Cloudy
6-19-73	2135	2140	A	22.5	22.5	SE	0-5	-	-	Cloudy
6-19-73	2145	2150	A	22.5	22.5	SE	0-5	-	-	Cloudy
6-19-73	1510	1515	B	24.5	24.0	W	5-10	W	.3	Cloudy
6-19-73	1525	1530	B	24.5	24.0	W	5-10	W	.3	Cloudy
6-19-73	2245	2250	B	22.0	22.0	-	-	-	-	Pt. Cloudy
6-19-73	2250	2255	B	22.0	22.0	-	-	-	-	Pt. Cloudy
6-19-73	1735	1740	F	24.0	23.9	Calm		SW	.2	Pt. Cloudy
6-19-73	1745	1750	F	24.0	23.9	Calm		SW	.2	Pt. Cloudy
6-19-73	0010	0015	F	22.0	22.0	-	-	Calm		Pt. Cloudy
6-19-73	0020	0025	F	22.0	22.0	-	-	Calm		Pt. Cloudy
7-20-73	2157	2202	A	23.0	23.0	N	5-10	NW	.3	Cloudy
7-20-73	2207	2212	A	23.0	23.0	N	5-10	NW	.3	Cloudy
7-19-73	1707	1713	A	23.0	23.0	Calm		SW	.1	Overcast
7-19-73	1717	1724	A	23.0	23.0	Calm		SW	.1	Overcast
7-19-73	1815	1822	B	24.4	24.4	Calm		SW	.1	Overcast
7-19-73	1825	1834	B	24.4	24.4	Calm		SW	.1	Overcast
7-20-73	2157	2204	B	21.5	21.5	N	0-5	NW	.4	Overcast
7-20-73	2213	2218	B	21.5	21.5	NE	0-5	NW	.4	Overcast
7-19-73	1936	1943	F	25.3	25.3	Calm		SW	.1	Overcast
7-19-73	1951	1959	F	25.3	25.3	Calm		SW	.1	Overcast
7-20-73	2335	2340	F	25.3	25.3	NE	0-5	-	-	Overcast
7-20-73	2350	2355	F	25.3	25.3	NE	0-5	-	-	Overcast
8-8-73	2315	2325	A	24.5	24.5	SE	10-15	SW	.4	Rain
8-8-73	2330	2340	A	24.5	24.5	SE	10-15	SW	.4	Rain
8-9-73	1423	1427	A	26.0	26.0	SW	0-5	W	.3	Fair
8-9-73	1435	1440	A	26.0	26.0	SW	0-5	W	.3	Fair
8-9-73	1525	1530	B	26.8	26.8	SW	0-5	W	.2	Fair
8-9-73	1540	1545	B	26.8	26.8	SW	0-5	W	.2	Fair
8-9-73	0005	0010	B	24.5	24.5	S	5-15	SW	.4	Fair
8-9-73	0020	0025	B	24.5	24.5	S	5-15	SW	.4	Fair

TABLE B3 continued.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
8-9-73	1644	1649	F	27.0	27.0	SW	0-5	W	.1	Fair
8-9-73	1700	1707	F	27.0	27.0	SW	0-5	W	.1	Fair
8-9-73	0140	0145	F	23.8	23.8	SW	10-15	SW	.3	Fair
8-9-73	0200	0205	F	23.8	23.8	SW	10-15	SW	.3	Fair
9-7-73	1045	1050	A	22.0	22.0	W	5-10	W	.4-.6	Pt. Cloudy
9-7-73	1055	1100	A	22.0	22.0	W	5-10	W	.4-.6	Pt. Cloudy
9-6-73	0015	0020	A	23.4	23.4	NW	10-15	W	.1	Fair
9-6-73	0030	0035	A	23.4	23.4	NW	10-15	W	.1	Fair
9-7-73	1005	1010	B	22.4	22.4	NW	5-10	W	.5	Pt. Cloudy
9-7-73	1015	1020	B	22.4	22.4	NW	5-10	W	.5	Pt. Cloudy
9-5-73	2305	2310	B	23.4	23.7	NW	10-15	W	.6	Fair
9-5-73	2315	2320	B	23.4	23.7	NW	10-15	W	.6	Fair
9-7-73	0910	0915	F	21.6	21.5	W	5-10	W	.6	Fair
9-7-73	0920	0925	F	21.6	21.5	W	5-10	W	.6	Fair
9-5-73	2125	2130	F	24.2	24.0	NW	10-15	W	.5	Pt. Cloudy
9-5-73	2145	2150	F	24.2	24.0	NW	10-15	W	.5	Pt. Cloudy
10-10-73	1435	1435	A	19.8	19.6	S	0-5	SW	0-.1	Fair
10-10-73	1456	1454	A	19.8	19.6	S	0-5	SW	0-.1	Fair
10-10-73	2330	2335	A	17.8	NR	S	0-5	SW	.1	Haze
10-10-73	2340	2345	A	17.8	NR	S	0-5	SW	.1	Haze
10-10-73	1525	1530	B	21.2	19.3	S	0-5	SW	.1	Fair
10-10-73	1545	1550	B	21.2	19.3	S	0-5	SW	.1	Fair
10-10-73	2230	2237	B	17.6	17.6	SE	0-5	Calm		Hazy
10-10-73	2240	2245	B	17.6	17.6	SE	0-5	Calm		Hazy
10-10-73	1640	1645	F	19.0	18.9	S	-	SW	.1	Hazy
10-10-73	1655	1700	F	19.0	18.9	S	-	SW	.1	Hazy
10-10-73	2120	2125	F	18.2	17.9	S	0-5	S	calm	Fog
10-10-73	2130	2135	F	18.2	17.9	S	0-5	S	calm	Fog
11-15-73	1532	1538	A	9.5	9.6	NW	15-20	W	1-1.3	Overcast
11-15-73	1540	1545	A	9.5	9.6	NW	15-20	W	1-1.3	Overcast
11-16-73	1215	1220	A	10.0	10.0	NW	0-5	NW	.6-1.0	Cloudy
11-16-73	1225	1230	A	10.0	10.0	NW	0-5	NW	.6-1.0	Cloudy

TABLE B3 continued.

Starting Date	Time		Station	Temperature C		Wind		Waves		Weather
	Start	Finish		Surface	Fish depth	Dir from	Speed mph	Dir from	Ht (m)	
11-15-73	1447	1455	B	10.3	10.1	SW	15-20	SW	.6-1.0	Cloudy
11-15-73	1500	1508	B	10.3	10.1	SW	15-20	SW	.6-1.0	Cloudy
11-14-73	1045	1050	B	10.7	10.7	NW	15-20	NW	.3	Fain
11-14-73	1055	1100	B	10.7	10.7	NW	15-20	NW	.3	Rain
11-14-73	2120	2125	F	11.0	11.0	S	5-10	SE	.1	Pt. Cloudy
11-14-73	2115	2120	F	11.0	11.0	S	5-10	SE	.1	Pt. Cloudy

TABLE B4. Date, starting time (EST) and some physical and limnological parameters measured at the time fish larvae tows were made.

Starting date	Starting time	Station	Diel period	Temperature (C)		Wind		Waves		Weather
				Surface	Fishing depth	Dir from	Speed (mph)	Dir from	Height (m)	
3-16-73	1305	A	Day	8.0	8.0	NW	15-20	NW	0.3-0.6	Overcast
3-16-73	1350	B	Day	8.0	8.0	NW	15-20	NW	0.3-0.6	Overcast
3-15-73	2215	A	Night	8.0	8.0	var	0-5	W	0.6-0.9	Cloudy
3-14-73	2030	B	Night	10.0	10.0	S	15-20	SW	0.6	Clear
4-13-73	1410	A	Day	7.5	7.5	NW	5	NW	0.3-0.6	Clear
4-13-73	1605	B	Day	8.1	8.1	NW	5	W	0-0.3	Clear
4-13-73	1725	F	Day	8.8	8.8	var	0-5	W	0-0.3	Clear
4-18-73	2335	A	Night	9.7	9.7	SE	0-5	Calm	Calm	Overcast
4-18-73	0035	B	Night	10.2	9.9	SE	0-5	Calm	Calm	Overcast
4-18-73	2130	F	Night	9.5	9.5	SE	0-5	Calm	Calm	Overcast
4-26-73	1015	C	Day	7.0	7.2	NE	10-15	N	0.3-0.6	Pt. Cloudy
4-26-73	0930	D	Day	7.0	7.2	NE	5	N	0.3-0.6	Overcast
4-26-73	1420	G	Day	7.2	7.6	N	18-20	N	0.6-0.9	Clear
4-26-73	1250	H	Day	7.4	6.8	N	12	N	0.3-0.6	Clear
4-29-73	0110	C	Night	6.4	6.2	E	9	N	0.6-0.9	Clear

TABLE B4 continued.

Starting date	Starting time	Station	Diel period	Temperature (C) Surface	Temperature (C) Fishing depth	Wind Dir from	Wind Speed (mph)	Waves Dir from	Waves Height (m)	Weather
4-29-73	0001	D	Night	7.0	7.0	N	0-5	N	0.6-0.9	Clear
4-28-73	2230	G	Night	7.5	7.7	NE	0-1	N	0.6-0.9	Clear
4-28-73	2125	H	Night	7.0	7.4	NE	0-1	N	0.6-0.9	Clear
5-18-73	1440	A	Day	12.5	12.5	SW	0-5	SW	Calm	Overcast
5-18-73	1545	B	Day	12.5	11.6	Calm	Calm	Calm	Calm	Overcast
5-18-73	1720	F	Day	12.1	12.1	Calm	Calm	Calm	Calm	Overcast
5-17-73	2040	A	Night	11.8	11.5	Calm	Calm	Calm	Calm	Clear
5-17-73	2200	B	Night	10.7	10.7	Calm	Calm	Calm	Calm	Clear
5-18-73	2245	F	Night	11.9	11.9	SE	5-15	SE	0-0.3	Cloudy
5-15-73	1729	C	Day	11.8	10.7	Calm	Calm	Calm	Calm	Clear
5-15-73	1618	D	Day	11.8	10.1	Calm	Calm	W	0.3	Clear
5-15-73	1412	G	Day	10.8	10.2	NW	12	NW	0.6-0.9	Clear
5-15-73	1328	H	Day	9.9	9.4	NW	12	NW	0.6-0.9	Clear
5-15-73	2109	C	Night	10.5	9.5	SW	10	SW	0-0.3	Clear
5-15-73	2217	D	Night	10.3	9.3	SW	10-12	SW	0.3	Clear
5-14-73	2048	G	Night	10.2	10.2	NW	2-5	NW	0.3	Clear
5-14-73	2120	H	Night	9.9	9.4	NW	5	NW	0.3	Clear
5-15-73	1030	M	Day	10.5	9.5	NW	10-12	NW	0.6	Clear
6-19-73	1610	A	Day	23.5	23.5	W	10	W	0.3	Cloudy
6-19-73	1500	B	Day	24.5	24.5	W	10	W	0.3	Cloudy
6-19-73	1730	F	Day	24.0	24.0	W	10	W	0.3	Cloudy
6-19-73	2130	A	Night	22.5	22.5	Calm	Calm	Calm	Calm	Pt. Cloudy
6-19-73	2240	B	Night	22.0	22.0	Calm	Calm	Calm	Calm	Pt. Cloudy
6-20-73	0005	F	Night	22.0	22.0	Calm	Calm	Calm	Calm	Pt. Cloudy
6-19-73	1330	C	Day	21.0	22.0	S	5-10	S	0-0.3	Cloudy
6-19-73	1136	D	Day	21.2	18.5	S	5-10	S	0.3	Pt. Cloudy
6-18-73	1720	G	Day	21.3	19.0	S	0-5	S	0-0.3	Pt. Cloudy
6-18-73	1515	H	Day	20.2	18.5	S	0-5	S	0-0.3	Pt. Cloudy
6-19-73	2230	C	Night	20.8	20.8	Calm	Calm	Calm	Calm	Pt. Cloudy
6-19-73	2112	D	Night	21.5	16.5	Calm	Calm	Calm	Calm	Pt. Cloudy
6-18-73	2213	G	Night	20.5	19.2	SE	10-15	S	0-0.3	Overcast
6-18-73	2104	H	Night	21.5	16.3	SE	10-15	S	0-0.3	Overcast
6-19-73	1504	E	Day	19.5	7.2	SW	8	SW	0-0.3	Cloudy
7-19-73	1650	A	Day	23.0	21.5	Calm	Calm	SW	0-0.3	Overcast
7-19-73	1751	R	Day	24.4	24.4	Calm	Calm	SW	0-0.3	Overcast

TABLE B4 continued.

Starting date	Starting time	Station	Diel period	Temperature (C)		Wind		Waves		Weather
				Surface	Fishing depth	Dir from	Speed (mph)	Dir from	Height (m)	
7-19-73	1920	F	Day	25.3	25.3	Calm	Calm	SW	0-0.3	Overcast
7-20-73	2150	A	Night	21.8	21.8	NE	0-5	N	0.3	Overcast
7-20-73	2049	B	Night	21.5	21.5	NE	0-5	N	0.3	Overcast
7-20-73	2325	F	Night	25.3	25.3	NE	0-5	N	0.3	Overcast
7-17-73	1205	C	Day	22.0	21.2	Calm	Calm	SE	0-0.3	Clear
7-17-73	1051	D	Day	21.1	18.2	SE	5-10	SE	Calm	Clear
7-16-73	1604	G	Day	22.2	22.2	NW	16	NW	0.6	Clear
7-16-73	1448	H	Day	22.0	18.5	N	15	NW	0.6	Clear
7-17-73	2046	C	Night	22.6	22.4	NE	3	Calm	Calm	Clear
7-17-73	2205	D	Night	20.5	15.5	SE	7	Calm	Calm	Clear
7-16-73	2041	G	Night	22.6	19.9	N	13	NW	0.3	Clear
7-16-73	2156	H	Night	21.8	18.2	NE	8	N	0-0.3	Clear
7-16-73	1702	E	Day	21.0	17.9	N	12	N	0.6-0.9	Clear
8-09-73	1410	A	Day	26.0	26.0	SW	5	W	0-0.3	Clear
8-09-73	1515	B	Day	26.8	26.8	SW	5	W	0-0.3	Clear
8-09-73	1645	F	Day	27.0	27.0	SW	5	W	0-0.3	Clear
8-08-73	2300	A	Night	24.5	24.5	SW	15	SW	0.3-0.5	Cloudy
8-08-73	2350	B	Night	24.5	24.5	SW	15	SW	0.3-0.5	Pt. Cloudy
8-09-73	0127	F	Night	23.8	23.8	SW	15	SW	0.3	Pt. Cloudy
8-22-73	1214	C	Day	11.3	9.2	S	6	E	0-0.3	Pt. Cloudy
8-22-73	1058	D	Day	11.3	8.5	E	2	E	0-0.3	Pt. Cloudy
8-22-73	1622	G	Day	16.5	12.4	N	0-5	N	0-0.3	Cloudy
8-22-73	1515	H	Day	17.0	15.8	Calm	Calm	Calm	Calm	Pt. Cloudy
8-21-73	2314	C	Night	14.3	12.2	NE	9	N	0.3-0.6	Pt. Cloudy
8-21-73	2002	D	Night	11.3	8.5	NE	9	N	0.3-0.6	Pt. Cloudy
8-22-73	2038	G	Night	16.3	14.9	SE	6	Calm	Calm	Cloudy
8-22-73	2150	H	Night	17.0	15.8	SE	6	Calm	Calm	Cloudy
8-22-73	1719	E	Day	21.0	11.1	N	5-8	N	0-0.3	Cloudy
8-21-73	1947	M	Night	14.0	10.0	NE	9	N	0.6	Pt. Cloudy
9-07-73	1135	A	Day	22.0	22.0	W	5-10	W	0.3-0.6	Pt. Cloudy
9-07-73	0955	B	Day	22.4	22.4	W	5-10	W	0.3-0.6	Pt. Cloudy
9-07-73	0850	F	Day	21.6	21.6	W	5-10	W	0.6	Clear
9-07-73	0005	A	Night	23.4	23.4	NW	10-15	W	0.9	Clear
9-06-73	2255	B	Night	23.4	23.4	NW	10-15	W	0.6	Clear

TABLE B4 continued.

Starting date	Starting time	Station	Diel period	Temperature (C) Surface	Temperature (C) Fishing depth	Wind Dir from	Wind Speed (mph)	Waves Dir from	Waves Height (m)	Weather
9-06-73	2115	F	Night	24.2	24.0	NW	10-15	W	0.3-0.6	Clear
9-18-73	1311	C	Day	13.0	12.0	SE	5	W	0.3-0.5	Pt. Cloudy
9-18-73	1050	D	Day	12.5	9.0	SE	5	W	0.3-0.5	Pt. Cloudy
9-17-73	1634	G	Day	11.5	11.0	NW	10-15	W	0.5-0.8	Overcast
9-17-73	1515	H	Day	12.2	10.0	SW	10	SW	0.3	Overcast
9-18-73	2336	C	Night	13.9	13.6	E	12	SE	0-0.3	Clear
9-18-73	2258	D	Night	14.2	13.5	E	5-10	SE	0-0.3	Clear
9-18-73	2203	G	Night	14.5	14.1	W	5	Calm	Calm	Clear
9-18-73	2019	H	Night	14.9	14.5	Calm	Calm	Calm	Calm	Clear
10-10-73	1430	A	Day	18.6	18.6	S	0-5	SW	0-0.3	Pt. Cloudy
10-10-73	1523	B	Day	19.3	19.3	S	0-5	SW	0-0.3	Pt. Cloudy
10-10-73	1630	F	Day	18.0	18.0	S	0-5	SW	0-0.3	Clear
10-11-73	2323	A	Night	17.8	17.8	SE	0-5	Calm	Calm	Fog
10-11-73	2010	B	Night	17.6	17.6	SE	0-5	Calm	Calm	Fog
10-11-73	2100	F	Night	17.9	17.9	SW	0-2	Calm	Calm	Fog
10-27-73	1007	C	Day	13.7	13.7	SE	15	SE	0.3	Pt. Cloudy
10-26-73	1636	D	Day	15.7	14.9	W	5-10	W	0-0.3	Clear
10-26-73	1459	G	Day	15.1	15.0	NW	5-10	NW	0.5	Pt. Cloudy
10-26-73	1345	H	Day	14.9	14.3	NW	5-10	NW	0.5	Pt. Cloudy
10-26-73	2308	C	Night	13.8	13.5	SE	5-10	NW	0.3	Clear
10-26-73	2159	D	Night	13.9	13.9	SE	2	NW	0.3	Clear
10-26-73	2020	G	Night	14.5	14.5	SE	2	NW	0.3	Clear
10-26-73	1835	H	Night	14.9	14.3	SE	2	NW	0.3	Clear
10-26-73	1153	E	Day	15.4	15.2	NW	10	NW	0.6	Pt. Cloudy
10-26-73	0916	M	Day	14.5	14.5	NW	10	NW	0.5	Pt. Cloudy
11-15-73	1520	A	Day	10.3	10.3	NW	15-20	W	0.9-1.3	Overcast
11-15-73	1440	B	Day	10.3	10.3	NW	15-20	W	0.9-1.3	Overcast
11-14-73	2348	A	Night	10.7	10.7	Calm	Calm	NW	0.6-0.9	Cloudy
11-14-73	2235	B	Night	10.7	10.7	NW	10-15	NW	0.3	Cloudy
11-14-73	2100	F	Night	11.0	11.0	S	5-10	S	0-0.3	Pt. Cloudy

separating species of *Coregonus* (subgenus *Leucichthys*) do not exist and, in fact, the validity of some species remains unsettled (Scott and Crossman 1973). To confound the problem, it has been suggested that various species may be introgressing (Wells and McLain 1973). The only adult *Leucichthys* that could be identified positively was the lake herring, *C. artedi*. Other adult *Leucichthys* and juveniles under 150 mm were pooled as unidentified coregonids (code XC). This latter group was probably made up of *C. hoyi* (bloater) and a few juvenile *C. artedi*, as these are the most abundant species of *Leucichthys* in southeastern Lake Michigan (L. Wells, personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service).

Difficulties were encountered distinguishing between *Cottus cognatus* and *Cottus bairdi*, due in large degree to inexperience on the part of the identifiers. Presently, with better identification references (McAllister 1964; D. Rottiers, personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service), study of identified specimens and greater experience, identification difficulties have been eliminated. It is probable that of the specimens originally identified as *C. bairdi*, the majority were actually *C. cognatus*, as this is the predominant species in samples taken from the study areas.

DATA MANIPULATION AND CALCULATIONS

Data from fish captured by seine, gillnet and trawl were recorded directly on a 75-column coding form. For each fish the following information was recorded, one fish per line: date and time of sample, type of gear, night or day series, station, water temperature at fishing depth where gear is used, a species code, a unique incrementing number, length, weight, sex and gonad condition. Special subsampling columns were used to designate the fish sampled from a larger group as well as columns to record the total weight of fish not examined (mass weight). A program was written to search the data for subsampled lots and then calculate the number of fish processed, the mean weight of those fish, and the number of fish present in the mass of fish not examined. The number of unsampled fish was assigned to length intervals proportionally, based on the number of measured fish found in length intervals. Fish were divided visually into many size classes when originally subsampled, to minimize error associated with this reconstruction of sample length-frequencies.

Fish data were keypunched, verified and then read onto disk files and tapes. For the bulk of our numerical analysis we used the Michigan Interactive Data Analysis System (MIDAS) which was developed by the Statistical Research Laboratory at the University of Michigan. MIDAS has very efficient programs for collating data, calculating statistics and depicting graphical relationships (Fox and Guire 1973). From MIDAS, we obtained summary statistics and histograms on sex ratios, seasonal gonad conditions, temperature-catch relationships, length-frequency histograms and length-frequency histograms of stomach-sampled fish.

It should be made clear that length-frequency histograms for the five major species included all fish captured. Thus for trawls and seines the

numbers of fish in each interval represent the combined numbers from both replicates, while for gillnets the numbers represent the corrected number per 12 hr in each interval. Other graphs usually depict mean catch, so that to compare these with length-frequency histograms their numbers should be doubled. Months when no or very few fish were caught were sometimes eliminated from length-frequency histogram figures.

Seining and trawling data were replicated (two hauls per station); in cases where only one of the two replicates was present, catch was doubled to facilitate comparisons.

Gillnet catches were adjusted to approximate numbers caught per 12 hr by making the assumption that catch was a linear function of time. In the field, nets were set for as close to 12 hr as possible, but the range for length of time the standard series gillnets were set was from 2.0 (storm came up) to 17.9 hr and averaged 9.5 ± 0.41 hr (N = 72). It is known that the foregoing assumption is not completely valid as gillnet catches per-unit-time might be expected to decrease as the net fills with fish, but the increased accuracy probably could not justify the cost of determining a precise relationship for each species.

Temperature-catch statistics for individual species were stratified by gear type (standard series only) and averaged over the number of stations. Standard error also was calculated and shown on the figures. The output consisted of frequency histograms of the mean number of fish caught by gear type over 2 C intervals. Water temperature used was recorded from the bottom where the particular gear was used. The following numbers of trawls, gillnets and seines were used: 110, 98 and 84 respectively in this evaluation. One should note that inferences drawn from these histograms are confounded not only by gear selectivity but also by seasonal presence of size classes. For example, adult smelt are generally present in the area only during spring, when water temperatures are relatively cold, approximately 8 C. Later in summer, when water temperatures are around 20 C, large numbers of young-of-the-year are recruited. Since the histograms are not stratified by size class, one should be careful when evaluating temperature relationships for each species. Numbers of fish caught within each temperature interval is a function of the biology of each species: age, temperature preference and acclimation temperature (Cherry et al. 1974). Present refinements in data analysis will permit temperature-catch histograms to be further stratified by size class and month.

DEFINITIONS

For purposes of this report a number of definitions were made. Fish larvae were arbitrarily designated as any fish 2.54 cm or smaller in total length, so that all fish greater than this will be treated in the adult and juvenile section. Young-of-the-year was abbreviated as YOY and refers to newly hatched fish in their first year of life. In this same context, age class 0 is sometimes used in discussions of the literature and is synonymous with YOY. Age classes 0, I, II, III etc. are mentioned occasionally and refer respectively to fish in their first year of life, second

year of life, etc. Fish change year classes in January. Other ambiguous terms used in this report are: offshore - usually refers to water depths greater than 9.1 m. In some instances when discussing seine catches, offshore indicates water depths greater than 2 m. Inshore - usually refers to water depths less than 9.1 m to shore. Beach zone = surf zone - water depths from 2 m to shore. Diel - refers to the 24-hr day. Diurnal - activity by daylight, occurring every day; opposite of nocturnal.

RESULTS AND DISCUSSION

DIVERSITY AND DISTRIBUTION OF FISH SPECIES IN THE STUDY AREA

Between May 1972 and January 1974, 45 fish species representing 16 families were captured from Lake Michigan in the vicinity of the Cook Plant (Table B5). Five of these species were captured only in 1972, seven other species were first encountered in 1973, and 32 species were captured during both years. Five species of fish have been taken only from the traveling screens from Cook Plant's intake system, including one encountered for the first time in January 1974.

Species composition of samples in the vicinity of the Cook Plant appears to be more diverse than numbers of species sampled near the following power generating facilities on Lake Michigan: Ludington Pumped Storage Project, 24 sp. (May 1973); Bailly Generating Station, 17 sp. (April 1973) and Zion Station, 24 sp. (December 1973). Fifty-five species were caught near Palisades Nuclear Power Plant (December 1973). Pooling our data with that from other studies, we estimate that the actual number of species occurring in the area of Lake Michigan near the Cook Plant is about 70 or 75, but some are extremely rare or transients that normally inhabit streams, inland lakes or protected bays.

Patterns of species movements as reflected by standard series catches (Table B6) illustrate the complexity of a natural system. Spatial and temporal fish migrations cause differential utilization of the study area throughout the year. As samplers of mobile animal populations, we are faced with the inherent problem of making inferences about population dynamics that are derived from static samples. Hopefully, our extensive sampling program of trawls, gillnets and beach seines will strengthen our inferences on adult fish movements. Coupled with our fish larvae sampling, we should be able to characterize the biology of many of the species inhabiting the Cook Plant area.

The following discussion will attempt to typify the seasonal distribution of species associations that variously inhabit the study area (Table B6). To avoid redundancy with the ensuing individual species accounts, only broad generalizations will be made on species distributions and factors influencing these distributions. Four major factors contributed to the patterns of species association observed throughout the year--temperature, spawning activity, diel activity and upwelling. Temperature may be the most important environmental parameter affecting our sampling. Since fish are poikilotherms, their behavior is dominated and limited by water

TABLE B5. Scientific name, common name and abbreviations for all species of fish captured from Cook Plant study areas in southeastern Lake Michigan from May 1972 through January 1974. Fish were taken with netting gear unless otherwise noted. Names assigned according to Bailey et al. 1970. An X denotes presence in that year.

Scientific and common name	Abbreviation	1972	1973
Acipenseridae			
Acipenser fulvescens Rafinesque Lake sturgeon	LG	X	X
Amiidae			
Amia calva Linnaeus[1] Bowfin	BF		X
Clupeidae			
Alosa pseudoharengus (Wilson) Alewife	AL	X	X
Dorosoma cepedianum (Lesueur) Gizzard shad	GS	X	X
Salmonidae			
Coregonus artedii Lesueur[2] Lake herring or Cisco	LH	X	X
Coregonus clupeaformis (Mitchill) Lake whitefish	LW	X	X
Coregonus hoyi (Gill)[2] Bloater	BL	X	X
Prosopium cylindraceum (Pallas) Round whitefish	RW		X
Oncorhynchus kisutch (Walbaum) Coho salmon	CM	X	X
Oncorhynchus tshawytscha (Walbaum) Chinook salmon	CH	X	X
Salmo gairdneri Richardson[3] Rainbow trout	RT	X	X
Salmo trutta Linnaeus Brown trout	BT	X	X
Salvelinus namaycush (Walbaum) Lake trout	LT	X	X
Osmeridae			
Osmerus mordax (Mitchill) Rainbow smelt	SM	X	X
Umbridae			
Umbra limi (Kirtland)[1] Central mudminnow	MM	X	X
Esocidae			
Esox lucius Linnaeus Northern pike	NP	X	X

TABLE B5 continued.

Scientific and common name	Abbreviation	1972	1973
Cyprinidae			
Couesius plumbeus (Agassiz) Lake chub	LC	X	
Cyprinus carpio Linnaeus Carp	CP	X	X
Notemigonus crysoleucas (Mitchill) Golden shiner	GL		X
Notropis atherinoides Rafinesque Emerald shiner	ES	X	X
Notropis hudsonius (Clinton) Spottail shiner	SP	X	X
Pimephales promelas Rafinesque Fathead minnow	PP		X
Rhinichthys cataractae (Valenciennes) Longnose dace	LD	X	X
Catostomidae			
Carpiodes cyprinus (Lesueur) Quillback	QL	X	X
Catostomus catostomus (Forster) Longnose sucker	LS	X	X
Catostomus commersoni (Lacépède) White sucker	WS	X	X
Moxostoma macrolepidotum (Lesueur) Shorthead redhorse	SR	X	
Ictaluridae			
Ictalurus melas (Rafinesque) Black bullhead	BB	X	X
Ictalurus natalis (Lesueur)[1,4] Yellow bullhead	YB		
Ictalurus punctatus (Rafinesque) Channel catfish	CC	X	X
Percopsidae			
Percopsis omiscomaycus (Walbaum) Trout-perch	TP	X	X
Gadidae			
Lota lota (Linnaeus) Burbot	BR	X	X
Gasterosteidae			
Pungitius pungitius (Linnaeus) Ninespine stickleback	NS	X	X

TABLE B5 continued.

Scientific and common name	Abbreviation	1972	1973
Centrarchidae			
Ambloplites rupestris (Rafinesque) Rock bass	RB		X
Lepomis cyanellus Rafinesque Green sunfish	GN	X	X
Lepomis gibbosus (Linnaeus)[1] Pumpkinseed	PS	X	X
Lepomis macrochirus Rafinesque Bluegill	BG		X
Micropterus dolomieui Lacépède Smallmouth bass	SB	X	
Micropterus salmoides (Lacépède) Largemouth bass	LB		X
Pomoxis nigromaculatus (Lesueur)[1] Black crappie	BC	X	X
Percidae			
Etheostoma nigrum Rafinesque Johnny darter	JD	X	X
Perca flavescens (Mitchill) Yellow perch	YP	X	X
Stizostedion vitreum vitreum (Mitchill) Walleye	WL	X	
Cottidae			
Cottus bairdi Girard[2] Mottled sculpin	MS	X	X
Cottus cognatus Richardson[2] Slimy sculpin	SS	X	X

1 Obtained only from the 1.5-cm (3/8 in) mesh basket which receives fish and other materials impinged on the traveling screens during periods of pumped water circulation.
2 Some difficulties in identification were experienced (see text).
3 Two phenotypes present.
4 Captured in January 1974.

TABLE B6. Numbers of fish caught during 1973 from standard series nets (seines, gillnets and trawls) in the inshore waters of southeastern Lake Michigan.

Species	Jan[1]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Percent	Total
AL[2]	-	0	1894	10633	3251	6802	13246	79942	767	31855	5	0	76.31	148395
SP	-	15	441	2716	3394	7421	1737	2525	869	1434	128	1	10.63	20681
SM	-	4	124	4132	823	955	295	8401	1503	341	15	0	8.53	16593
YP	-	5	34	16	44	1497	650	949	257	398	27	0	1.99	3877
TP	-	0	1	47	157	1565	714	522	170	343	23	0	1.82	3542
JD	-	0	0	13	47	58	17	31	11	30	0	0	.11	207
WS	-	1	6	8	15	28	27	36	47	31	0	0	.10	199
LT	-	0	1	1	2	2	10	21	58	34	61	0	.10	190
XC	-	0	0	0	2	26	60	37	2	21	0	0	.08	148
LS	-	1	1	10	18	15	38	1	1	1	0	0	.04	86
RT	-	1	1	15	30	13	6	11	1	3	5	0	.04	86
SS	-	0	0	44	14	3	0	6	5	7	1	0	.04	80
BT	-	1	0	2	6	33	18	4	4	8	0	0	.04	76
ES	-	1	2	1	6	1	2	11	15	8	2	0	.03	49
LD	-	2	0	2	4	3	3	4	22	0	1	0	.02	41
NP	-	0	0	0	0	2	0	1	9	15	11	0	.02	38
CM	-	0	6	3	10	7	0	0	4	2	0	0	.02	32
CP	-	0	0	2	2	14	1	2	7	0	0	0	.01	28
CH	-	0	1	2	5	6	3	3	3	3	0	0	.01	26
GS	-	0	0	0	0	0	0	0	0	1	22	0	.01	23
NS	-	0	1	1	12	5	0	0	0	0	0	0	.01	19
MS	-	0	0	9	3	2	0	0	0	2	0	0	.01	16
BG	-	0	0	0	2	3	0	1	0	0	5	0	.01	11
CC	-	1	0	0	0	1	0	2	0	2	5	0	.01	11
BR	-	0	0	4	0	2	0	0	0	0	0	0	<.01	6
LW	-	0	0	0	1	1	0	0	0	0	0	0	<.01	2
BB	-	0	0	1	0	0	1	0	0	0	0	0	<.01	2
PP	-	0	0	0	1	0	1	0	0	0	0	0	<.01	2
RB	-	0	0	0	0	1	0	0	0	0	1	0	<.01	2
GL	-	0	0	2	0	0	0	0	0	0	0	0	<.01	1
LB	-	0	0	1	0	0	0	0	0	0	0	0	<.01	1
Totals	-	32	2513	17665	7849	18466	16829	92510	3755	34539	312	1		194471

[1]See text for explanation of times when limited sampling (non-complete standard series) was performed.
[2]See Table B5 for definition of species abbreviations.

temperature. Many differences in abundance between Cook Plant and Warren Dunes are probably due to differences in local temperature, which in conjunction with instinctive behavior patterns regulate the timing and extent of spawning activity.

Spawning activity accounted for much of the monthly variation in numbers of rainbow smelt, trout-perch, perch and alewife. Many of the interactions in ANOVA were directly traced to spawning. In general, fish which wintered in the offshore zone began to move inshore in spring. After spawning they generally dispersed more widely into warmer water and with the onset of winter moved back into deeper water. The sequence of spawning appeared to be: April-May, smelt and sculpins; late June-early July, alewife, yellow perch and spottail; July-August, trout-perch, spottail and alewife. Ripe lake trout were found in the area in the fall, but no evidence of successful natural recruitment has been found anywhere in the entire lake (Wells and McLain 1973). Intertwined with spawning behavior is diel activity which is undoubtedly related to feeding activity. Nocturnal behavior by trout-perch and to some extent by alewife and spottail, crepuscular activity of yellow perch and diurnal activity of YOY of most species illustrate the wide variation in temporal activity. Although upwellings are a temperature phenomenon, they are also a mechanical phenomenon. In late summer, large bodies of cooler water displacing the inshore water caused many fish to leave the area (alewife, spottail, trout-perch and to some extent yellow perch) and at least four species to enter (smelt, lake trout, bloater and sculpin). These four factors overlap in their effects, and determining relationships proved very difficult.

Poor weather conditions during December, January and February limited our sampling to gillnets and a few beach seines. While more extensive sampling would have undoubtedly increased catches, sets that were fished indicate low numbers of fish present during winter. The immediate beach zone is very cold, and fish movement, particularly warm-water species, is very slow when temperature is low. Thus gillnets, which depend on fish movements, and beach seines underestimate fish numbers in winter. Spottails comprised the bulk of the winter catch along with a few suckers, rainbow trout, burbot and smelt. Spottails probably inhabit the study area the entire year.

The spring catch was heavily influenced by influx of adult fish seeking warmer water and suitable spawning areas. No trawling was done in March, so our estimates of numbers of smaller fish in the offshore area are probably too low. Few fish were caught in beach seines, probably due to the cold water. Alewife, spottails and smelt respectively were the most abundant species in March. By April the spawning run of smelt was evident from seining and trawling catches. In May, water temperatures had increased and the total body of warm water was larger. Numbers of adults of all prominent species were moderate, indicating dispersal through the warm-water area. Smelt move back into deeper water following spawning. Spottails did not disperse as much as the other species.

During June, July and August the bulk of spawning took place and many YOY were recruited, especially in August. The total number of fish caught

in June was third highest for the year. Spawning adults of warm-water species such as the alewife, spottail, yellow perch, trout-perch and johnny darter crowded within the 9.1-m contour. For most of these species, spawning activity was probably normally distributed about June, extending from May through July. In July most species declined in numbers from their June peaks. Apparently after spawning, adults began to disperse and were not as concentrated in shallower waters. The peak number of coregonids (XC) in July is unexplainable, but corresponds with the findings of Wells (1968). The overall high catch of all abundant species in August was influenced by two components. First, newly recruited YOY of alewives, yellow perch and spottail shiners were very abundant in the beach zone. Second, a cold-water upwelling (Seibel and Ayers 1974) apparently forced large numbers of both adult and juvenile smelt into the trawling zone. These combined effects resulted in the highest monthly catches of the year. We concluded that because of the massive effects of upwellings on fish movements, it will be imperative to have continuous accurate water temperature data at the Cook Plant.

As water temperature declined in the fall (September, October, November), most species began their offshore movement into deeper water. In contrast to August and October, beach seining in September caught very few YOY alewife or spottails. High wind and waves decreased the effectiveness of our seining and probably made the beach zone inhospitable for YOY. In conjunction with the inclement weather during sampling, an ongoing upwelling was forcing the warmer water farther out into the lake. The majority of adults and juveniles probably followed the warm-water body, accounting for the low overall catch. Smelt, a cold-water species, was the most abundant fish caught in September. While some of the formerly most abundant species were caught in low numbers in September, some less abundant species were at their yearly peaks in September. Largest catches of white suckers, emerald shiners and longnose daces were taken in September. Lake trout spawn in late fall and would be expected in great numbers then. White suckers were caught mainly in gillnets and trawls. Emerald shiners and longnose dace were caught in seines during the warmer part of the month. Their presence in abundance in the surf zone is unexplainable, but may be related to the upwelling that occurred.

October and November temperatures were more typical of the overall downward trend expected in fall. Typical, however, is a precarious word for fall, due to frequent upwellings which introduce high variability in fall temperatures. Numbers of warm-water species declined from summer peaks because of adults moving offshore, and natural mortality had lowered the numbers of YOY. Lake trout numbers were still high, reflecting the numbers of ripe adults seeking shallow areas for spawning. Alewife numbers declined drastically in November. Apparently the bulk of the population had moved offshore into deeper waters or farther south in the lake. Appearance of gizzard shad in November may be due to southern migrations to warmer waters.

SPECIES CATCHES BY GEAR TYPE

As with most fishing methods, sampling is biased by degree of efficiency

of the gear. Gear we used varied widely in its ability to catch fish. Seines and trawls (active fishing gear) were more effective in catching smaller fish of a given species; larger fish can usually avoid these nets. Gillnets (passive fishing gear) were effective in catching all sizes of fish except very small individuals, but susceptibility is dependent on fish movements, fish morphology and probably time of day.

Relative effectiveness of the three types of gear in capturing different species at Cook Plant and Warren Dunes stations was compared (Tables B7, B8). Efficiency varied considerably in capturing a given species. Because all sizes are included in the tables, little can be said about gear selectivity for different size groups of a species. Some gear selectivity is mentioned in the discussion of individual species. Since a complete standard series of nets was not obtained (see Methods Section, Missing Samples), some bias toward warmer month catches was unavoidable but not thought to change overall conclusions to any significant degree. Because there was one more seining station at the Cook Plant, actual numbers of fish captured at Cook and Warren Dunes (Tables B7, B8) cannot be compared directly. However, if gear selectivity and efficiency were the same at all stations (there appears to be no reason to refute this) then percentages can be compared and will be discussed below.

There were no major differences in percentages of fish caught using the three gear types during day and night between Cook and Warren Dunes stations (Tables B7, B8). The various gear were equally efficient at catching a given species at the two different areas.

Small species (i.e., alewife, spottail, smelt, trout-perch, johnny darter, emerald shiner, longnose dace, gizzard shad and fathead minnow) were caught mainly by seining and to a lesser degree by trawling. Smaller individuals of larger species (i.e., juveniles of rainbow trout, yellow perch and brown trout) were also caught by seining. Larger species (yellow perch, white and longnose sucker, lake trout and burbot) were caught mainly by gillnets.

Overall, more species were caught at night than during the day. Probably the fishing gear is more efficient at night, because fish are less able to sense nets and are usually more active at night (depending on species). Fish may also be more randomly distributed at night than during the day because of spawning and foraging activities.

Several differences between day and night catches of certain species were quite evident. More alewives were caught during the day than at night, which is especially pronounced in seine data. More spottails were caught in seines during daytime than during night at Cook stations. At Warren Dunes stations more spottails were caught by all gear at night than during the day. More trout-perch were caught at night than during the day, indicating pronounced nocturnal behavior.

To show overall composition and predominant fishes caught with the three gear types at Warren Dunes and the Cook Plant, standard series day and night catches were pooled over months (Figs. B2-4). Alewives

TABLE B7. Numbers and percentages of fish caught during the day in seines, gillnets and trawls from the standard series nets fished during 1973 in the inshore waters of southeastern Lake Michigan.[1]

Species	Cook Plant Stations (A,B,C,D)						Warren Dunes Stations (F,G,H)					
	Seine		Gillnet		Trawl		Seine		Gillnet		Trawl	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
AL[2]	54414	89.5	3143	5.2	3263	5.4	47893	90.0	2874	5.4	2452	4.6
SP	7054	81.5	1014	11.7	585	6.8	1854	71.4	382	14.7	362	13.9
SM	841	22.8	131	3.6	2719	73.7	6	0.1	190	3.0	6098	96.9
YP	208	15.8	608	46.2	499	38.0	76	7.9	465	48.1	426	44.1
TP			7	1.5	471	98.6			15	4.5	320	95.5
JD	3	7.7			36	92.3					17	100.0
WS	1	6.7	12	80.0	2	13.3	5	10.6	37	78.7	5	10.6
LT			13	92.9	1	7.1			19	100.0		
XC	1	7.7	2	15.4	10	76.9			13	31.7	28	68.3
LS	1	16.7	5	83.3					15	88.2	2	11.8
RT	24	96.0	1	4.0			11	100.0				
SS					15	100.0					4	100.0
BT	4	57.1	3	42.9			10	76.9	3	23.1		
ES	28	100.0					5	100.0				
LD	5	100.0										
NP	3	23.1	10	76.9					9	100.0		
CM			2	100.0			3	42.9	4	57.1		
CP	4	80.0	1	20.0								
CH	5	100.0							2	66.7	1	33.3
GS	6	100.0										
NS					1	100.0						
MS											1	100.0
BG	1	100.0									1	100.0
CC	1	50.0			1	50.0						
BR			1	100.0					2	100.0		
LW											1	100.0
BB												
PP	2	100.0										
RB												
GL												
LB												
Total	62606		4953		7603		49863		4030		9718	

[1]See text for explanation of times when limited sampling (non-complete standard series) was performed.
[2]See Table B5 for definition of species abbreviations.

TABLE B8. Numbers and percentages of fish caught at night in seines, gillnets and trawls from the standard series nets fished during 1973 in the inshore waters of southeastern Lake Michigan.[1]

	Cook Plant Stations (A,B,C,D)						Warren Dunes Stations (F,G,H)					
	Seine		Gillnet		Trawl		Seine		Gillnet		Trawl	
Species	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
AL[2]	16488	83.1	2058	10.4	1298	6.5	6163	42.5	3184	21.9	5165	35.6
SP	2791	56.6	1044	21.2	1097	22.2	2022	45.0	1270	28.2	1206	26.8
SM	555	35.8	28	1.8	968	62.4	1102	21.8	219	4.3	3736	73.9
YP	158	21.5	290	39.5	286	39.0	184	21.4	227	26.4	450	52.3
TP	45	4.3	102	9.9	888	85.8	35	2.1	157	9.3	1502	88.7
JD	4	4.1			93	95.9					54	100.0
WS	19	44.2	22	51.2	2	4.7	6	6.4	86	91.5	2	2.1
LT			120	98.4	2	1.6			34	97.1	1	2.9
XC			29	64.4	16	35.6			40	81.6	9	18.4
LS			19	90.5	2	9.5	2	4.8	39	92.9	1	2.4
RT	37	94.9	2	5.1			11	100.0				
SS	7	16.7			36	85.7	1	5.6			17	94.4
BT	36	97.3			1	2.7	18	94.7	1	5.3		
ES	16	100.0										
LD	34	100.0					2	100.0				
NP	2	13.3	11	73.3	2	13.3			1	100.0		
CM	6	31.6	13	68.4					4	100.0		
CP	10	58.8	7	41.2			6	100.0				
CH	4	40.0	6	60.0			1	12.5	7	87.5		
GS	8	100.0					9	100.0				
NS	8	80.0			2	20.0	2	25.0			6	75.0
MS	3	25.0	1	8.3	8	66.7					3	100.0
BG	4	100.0					4	80.0			1	20.0
CC			7	100.0			2	100.0				
BR			1	100.0					1	50.0	1	50.0
LW											1	100.0
BB	2	100.0										
PP												
RB							1	50.0	1	50.0		
GL	1	100.0					1	100.0				
LB	1	100.0										
Total	20239		3760		4701		9572		5271		12155	

[1]See text for explanation of times when limited sampling (non-complete standard series) was performed.
[2]See Table B5 for definition of species abbreviations.

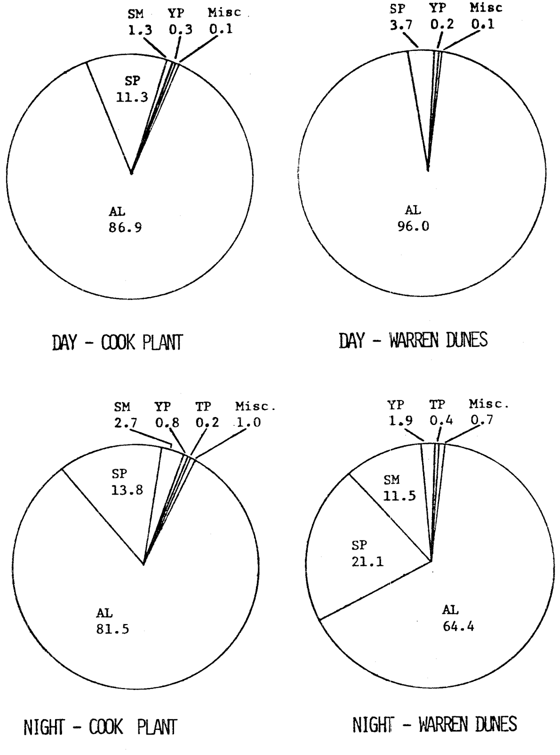


FIG. B2. Comparison of percentage species composition by numbers of seine catches during day and night at Cook Plant and Warren Dunes. See Table B5 for definition of species abbreviations.

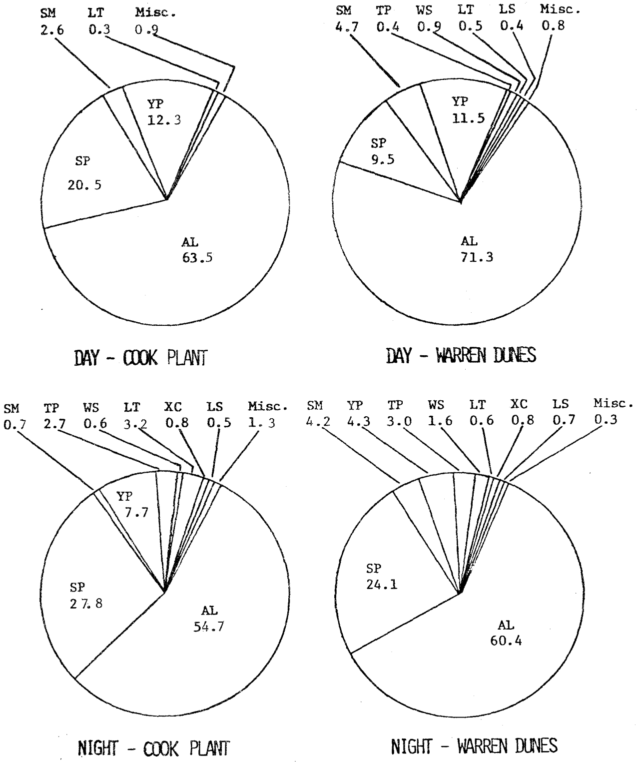


FIG. B3. Comparison of percentage species composition of gillnet catches during day and night at Cook Plant and Warren Dunes. See Table B5 for definition of species abbreviations.

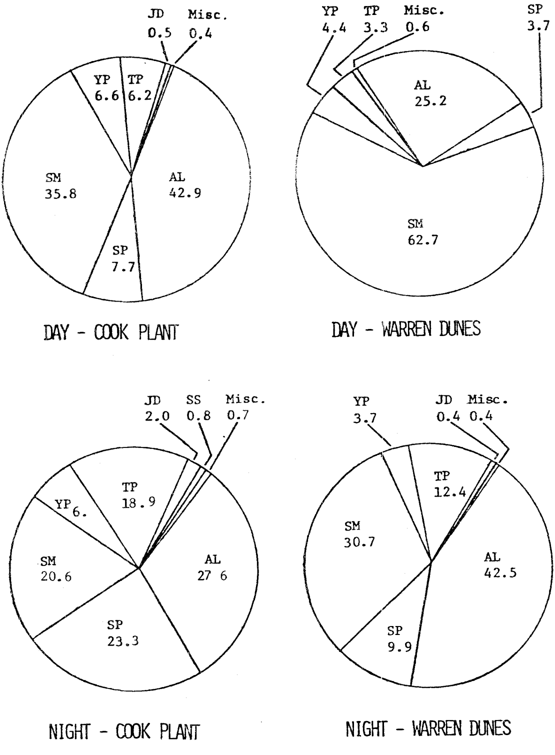


FIG. B4 . Comparison of percentage species composition of trawl catches during day and night at Cook Plant and Warren Dunes. See Table B5 for definition of species abbreviations.

dominated seine catches (Fig. B2) during day and night at both areas. Adults and juveniles utilized the beach zone, adults in spring and YOY in late summer and fall; both were quite vulnerable to seining. Other species, especially spottail shiners, were caught by seining during the day, but their percentage of the total catch increased at night. Smelt were more prevalent in the catch at night in spring. They were mainly ripe adults, probably seeking spawning areas. Most trout-perch appeared in seine catches at night. Later analysis of stomach contents may reveal if greater species diversity at night in the beach zone is related to feeding behavior.

Some differences in seine catch composition between Cook and Warren Dunes stations existed. These differences were primarily between percentages of spottails and smelt, mostly adults, caught in each area. Spottails and smelt were scarce during the day at Warren Dunes but abundant at night. Differences between night and day at Cook stations were not as pronounced but most of the day catch of smelt was taken at the sheltered station B and this catch was responsible for making day and night smelt catches similar at the Cook Plant.

As with seine catches, gillnet catch composition (Fig. B3) was generally similar between Cook and Warren Dunes areas. Again, alewives dominated catches day and night in both areas and diversity was greater at night than during the day. Greater numbers of large species caught in gillnets were reflected in larger fish comprising a greater proportion of the gillnet catch compared to other gear catches. Lake trout, white and longnose suckers were caught in greatest numbers by gillnetting (Tables B7 and B8). These larger fish can effectively avoid seines and trawls but are vulnerable to gilinets. Differences in selectivity of gear underscores the necessity of utilizing a variety of fishing gear to estimate total fish populations in a given ecosystem.

Some differences in gillnet species composition at night and day between the two areas were found. Yellow perch comprised a greater percentage of the catch during day than at night in both areas. They were apparently more active in the inshore zone during the day. More spottails were caught at night than during the day from both areas, but differences were most pronounced at Warren Dunes.

Composition of the trawl catch (Fig. B4) was not dominated by alewives to the same extent as seine and gillnet catches. Trawl catch composition was more variable between areas and especially between day and night.

Species composition of night trawl catches at the Cook Plant and Warren Dunes was generally similar. During day and night spottails comprised a greater proportion of the catch at Cook Plant, while smelt (mostly yearlings and YOY) made up a greater proportion at Warren Dunes. Percentages of yellow perch, trout-perch and johnny darters were similar between the two areas. Smelt comprised the majority of the day catch from trawls at Warren Dunes. Although smelt constituted one-third of the day catch at Cook, they were not as abundant as at Warren Dunes. Evidently

smelt utilized the Warren Dunes area to a greater extent than at Cook. Day smelt catches were almost twice as large as corresponding night catches in both areas. It appears the nocturnal vertical migration found by Ferguson (1965) for Lake Erie smelt is also occurring in Lake Michigan yearling and YOY smelt. Trout-perch comprised a greater proportion of the night trawl and gillnet catches than day catches.

MOST ABUNDANT SPECIES

Alewife

The alewife is an anadromous marine herring indigenous to lakes and streams of the Atlantic coastal drainage from Newfoundland to North Carolina (Scott and Crossman 1973; Winters et al. 1973). During the mid-1800's, alewives reached Lake Ontario, probably via the Erie Canal (Smith 1970). In the 1900's large numbers spread throughout the Great Lakes, where they became landlocked. Alewives are also landlocked in some of the Finger Lakes and other lakes of New York (Odell 1934). They were first discovered in northern Lake Michigan in 1949 (Miller 1957) and by 1953 had spread to the southern end of the lake. Alewives now occur in all the Great Lakes, reaching extreme abundance in some years.

Because of their great abundance and wide distribution, Lake Michigan alewives have had a considerable ecological and economic impact. In 1965 and 1966 alewives reached an apparent population peak in Lake Michigan (Brown 1972; Colby 1973), followed by a massive dieoff in 1967 (Brown 1968). Mortality was estimated at several billion fish (Wells and McLain 1973). Beaches littered with dead alewives received wide public attention and resulted in loss of tourist revenue. Annual mortalities of alewives are characteristic of landlocked populations and have been reported since the 1800's (Pritchard 1929). Periodic mortalities are apparently related to inability of alewives to adapt to extreme temperature fluctuations after harsh winters in the Great Lakes (Brown 1968; Colby 1971, 1973). In addition to the nuisance from massive dieoffs, alewives often cause physical and economic damage by clogging water intakes of steel mills, power plants and municipal water filtration plants (Wells and McLain 1973).

Besides affecting man's uses of Lake Michigan water, the alewife has had a marked effect on Lake Michigan fish stocks. Lake herring, lake whitefish and emerald shiner populations have decreased as alewife abundance increased (Smith 1970). These shallow-water planktivores have been apparently out-competed by the ubiquitous alewife. Declining stocks of yellow perch may also be related to the alewife (Smith 1968). Although reasons for declines in Lake Michigan fish populations are difficult to ascertain, the alewife has undoubtedly played a major role either directly or indirectly in these changes.

In contrast to detrimental effects, alewives have also had some beneficial effects on the ecology of Lake Michigan. Lake Michigan alewives have been caught commercially for use as fish meal and pet food. Commercial

production of alewives is strongly influenced by market demand, but catches increased from 1×10^5 kg (2.2×10^5 lb) in 1957 to 2.1×10^6 kg (4.7×10^6 lb) in 1962 and reached a peak of 2.2×10^6 kg (4.9×10^6 lb) in 1967 (Wells and McLain 1973). In addition to commercial utilization by man, alewives are important forage fish. Larger piscivorous fishes such as burbot and lake trout prey upon alewives (Scott and Crossman 1973) and we have found that large yellow perch fed heavily upon large adult alewives during spring and early summer. From surveys at the Finger Lakes, Odell (1934) reported alewives in stomachs of walleye, northern pike, bass, pickerel, cisco, lake trout, rainbow trout, eel and yellow perch. In Lake Michigan, Wagner (1972) found that when alewives were abundant they were preyed upon heavily by northern pike, smallmouth bass, walleye, burbot and bowfin. The abundant supply of alewives, upon which salmon prey, has made possible the successful salmon stocking programs in Lake Michigan in recent years (Wells and McLain 1973).

Alewives constituted the vast majority of the catch from our fishing efforts in 1973 (Table B6). Alewives were collected during spring, summer and fall by all fishing gear employed (Tables B7, B8). Records indicate that alewives utilize all depths in southeastern Lake Michigan during their annual movements (Wells 1968; Brown 1972). They are found in deeper water in the winter, migrate inshore in spring, disperse widely in warm summer waters and return to deeper water in fall. This seasonal migration closely follows seasonal water temperature changes.

Statistical Analysis of Alewife Catch

Trawls. Results of ANOVA (Table B9) for trawl catches of alewives illustrate the highly complex pattern inherent in sampling an abundant pelagic fish species. Four highly significant ($P = <.005$) first-order interactions and two significant ($P = <.01$) second-order interactions were present. Since these confounded interpretation of main effects, higher order interactions must be examined and analyzed in terms of a suitable biological analogue. Unfortunately, a satisfactory explanation or confirmation of these interactions as a distinct biological pattern must await at least another year of preoperational data.

As a first approximation, most of the interactions can be attributed to the general inshore migration of alewives commencing in April, continuing through June, and vertical migration of schooling fish which at various times remove alewives from the trawling depths, particularly at 9.1 m. Greater catches at 6.1-m depth than at 9.1 m, high catches in the seines, and personal observations of surfacing fish at night tend to support activity in the upper water strata. One echo-recording trace of this phenomenon on 13 May 1974 detected schooling fish between 2.1 and 5.2 m on the 6.1-m contour at the Cook Plant. Additional echo soundings would prove helpful in confirming or rejecting this phenomenon. Gillnet studies at the Point Beach Nuclear Plant also indicated vertical variation and surface activity (Wis. Elec. Power Co. and Wis. Mich. Power Co. 1973). In contrast to our bottom-set gillnets, both surface and bottom gillnets were fished by Point Beach researchers. They found that surface gillnets

TABLE B9. Summary of analysis of variance for alewives caught in trawls in the Cook Plant study area from April through October 1973.

Source of variation	df	Adjusted mean square[1]	F-statistic	P
AREA	1	3.20860	26.91	<.01
MONTH	6	2.58857	21.71	<.01
DEPTH	1	2.23550	18.75	<.01
TIME of day	1	1.11313	9.34	<.01
AxM	6	1.54793	12.98	<.01
AxD	1	.06744	.57	NS[2]
AxT	1	4.13170	34.65	<.01
MxD	6	.22304	1.87	NS
MxT	6	5.91008	49.57	<.01
DxT	1	.97695	8.19	<.01
AxMxD	6	.27586	2.31	<.05[3]
AxMxT	6	.46255	3.88	<.01
AxDxT	1	.02288	.19	NS
MxDxT	6	.68968	5.78	<.01
AxMxDxT	6	.15731	1.32	NS
Within cell error	54[4]	.119235		

[1] Mean squares were multiplied by harmonic cell size/maximum cell size (n_h/N = .966) to correct for 2 missing observations where the cell mean was substituted.

[2] Not significant (P >.05).

[3] Not significant (.01 <P <.05).

[4] Two degrees of freedom were substracted to correct for 2 missing observations where the cell mean was substituted.

were far more effective than bottom nets, capturing alewives by a ratio of better than 2 to 1. Thus in terms of our trawling efforts, surface activity and vertical variations contributed to variability in the model and indirectly, at least, to significance of interaction terms.

The MONTH x AREA x TIME of day interaction is illustrated in Fig. B5. Daytime catches in both areas appeared to be the same, the only exception being the very high April catch at the Cook Plant. It appears unlikely that alewives would reverse daytime preferences between areas over the study period. Thus these discrepancies are probably attributable to the aforementioned vertical variation. At night, however, consistently higher catches at Warren Dunes may indicate a decided preference for this more gently sloping area. Here again further evidence will be necessary.

The MONTH x DEPTH x TIME of day interaction (Fig. B5) shows diel variation in trawl catch over months for 6.1-m and 9.1-m stations. Daytime activity in the trawling range was consistently low at both depths except during April when one of the largest catches obtained was recorded at 6.1 m. By May nocturnal activity became dominant. This does not mean that a shift to nocturnal behavior had occurred but simply that alewives were more susceptible to the trawl. Nocturnal activity continued through July. In August there was no discernible difference between day and night catches at either depth. YOY, which comprised most of the August trawl catch, may not have developed any distinct diel preference and thus remained equally susceptible. In September the pattern again shifted to daytime activity with consistently higher day catch at both depths. August and September catches, however, should be suspect since upwellings occur frequently and rapidly in August and September (Wells 1968; Seibel and Ayers 1974).

One should bear in mind that preceding explanations and analysis of variance were based upon only 1 yr data. Consequently, continued sampling efforts will aid in our interpretation of alewife biology in inshore waters. In particular, significance of interaction terms may vary from year to year. Using this premise, two alternative mean-square pooling strategies were attempted. In the first instance, the precarious assumption that all second- and third-order interactions were insignificant was made. A new, pooled mean-square error term was used to recalculate the test statistic. Significance of TIME as a main effect was reduced to $.01 < P < .05$ but significance of other main effects and first-order interactions remained the same as before. In the second case, all nonsignificant ($P > .05$) interaction terms were pooled into the error term. All significant terms in the original ANOVA were unchanged by this pooling strategy.

Pooling interaction sums of squares into the error term should be avoided, since not much is known about the operating characteristics of such procedures. While pooling increases degrees of freedom in the test statistic, it can lead to incorrect results if the interactions are incorrectly assumed to be zero, since there is an increase in the expected mean square, hence decreasing sensitivity of the tests (Scheffé 1959). Here again need for an additional year's data is illustrated.

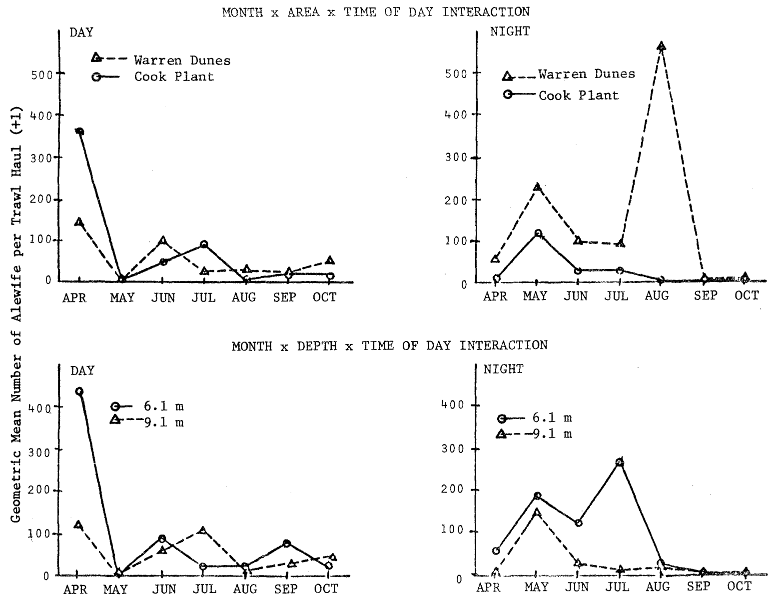


FIG. B5 . Geometric mean number of alewives caught in duplicate trawl hauls during the day and at night at Cook Plant and Warren Dunes (depth pooled by month) and during the day and night at 6.1 and 9.1 m (areas pooled by month) in southeastern Lake Michigan, 1973.

Gillnets. Results of nonparametric tests showed no significant differences between areas or depths (see Table B10). As expected, differences among catches over months were highly significant ($P < .001$). The ensuing discussion will examine the seasonal variation in gillnet catch. Hopefully when coupled with data from other sampling gear we will be able to delineate the biology of alewives in the inshore water of southeastern Lake Michigan.

Gillnets are good indices of adult alewife abundance because of their selectivity for larger size groups (Fig. B6). Alewives were first caught in gillnets in March, indicating that adults had moved into the inshore zones. April catches were high, as was found during trawling. In May, gillnet catches dropped considerably at all stations. It would be unlikely for adult alewives to reverse this initial spring migration only to return again in June, which supports the contention that vertical migration results in much of the variability. Alternatively, alewives may be attracted to the warmer nearshore waters in April, then disperse widely as warmer areas increase from shore, returning in greater numbers in June to spawn. June catches were very high, apparently resulting from spawning activity. August catches were high only at the 6.1-m station at Warren Dunes; coupling this evidence with the trawl catch may indicate that alewives concentrate more heavily in the Warren Dunes area. Future analysis by the multivariate techniques of principal components may illuminate these differences.

Seines. Seine catches indicated that some yearlings and YOY alewives use the beach zone; adult alewives were numerous along the beach only in April and May at night (Fig. B7). Absence of adult alewives from the beach zone during the major portion of the year may be a thermally regulated

TABLE B10. Summary of nonparametric analyses of alewives caught in standard series gillnets in the Cook Plant study areas from April through October 1973. NS = not significant; S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic		Mann-Whitney U statistic	
		value	P	value	P
Month (Apr-Oct)	6	45.557	.0000 S	----	----
Depth (6.1; 9.1m)	1	.18755	.6650 NS	642.5	.6648 NS
Area (Cook Plant; Warren Dunes)	1	.21913	.6397 NS	602.0	.6395 NS

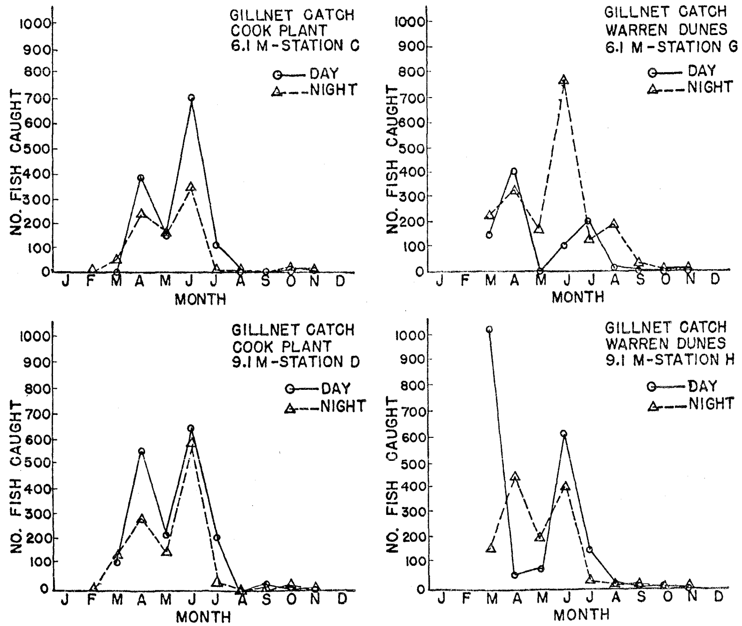


FIG. B6. Number of alewives caught in gillnets set during the day and night once per month February through December 1973 in southeastern Lake Michigan.

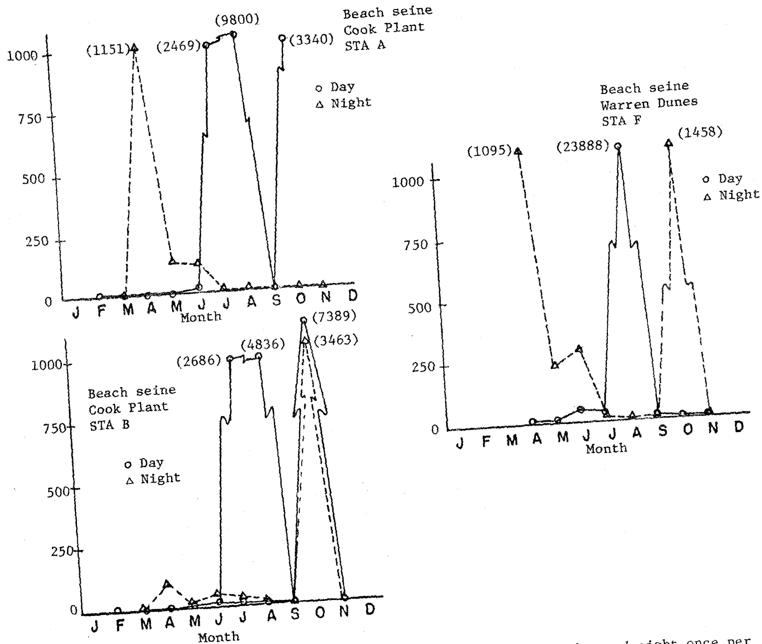


FIG. B7. Mean number of alewives caught in seines fished during day and night once per month February through November 1973 in southeastern Lake Michigan.

phenomenon, since temperatures fluctuate more rapidly in this zone than in the main body of the lake. YOY used the beach zone almost exclusively during the day in July and August as indicated by very high day catches of YOY alewives from all stations except Warren Dunes in July. August trawl catches indicated that YOY were not out to 9.1 m off Warren Dunes. It is possible YOY may follow thermal gradients to a greater extent than do adults. Rapid cooling of beach-zone waters after sunset may cause offshore movement to warmer waters. September catch was zero at all stations but this is undoubtedly related to poor weather conditions. High winds and waves undoubtedly dispersed alewives to deeper waters. Furthermore, 1972 data (Jude et al. 1972) and 1974 data showed high catches of YOY in September. In 1973, large numbers of YOY were again present in October, but by November YOY had apparently moved beyond the range of sampling gear to mid-water depths, a phenomenon documented by Brown (1968).

Due to excessive zeros in the data matrix, seining data were analyzed using the nonparametric Kruskal-Wallis statistic (Table B11). As expected, station effects and area effects were insignificant ($P > .05$); month effects were highly significant ($P < .05$).

Seasonal Distribution by Age-size Class

Alewives utilize all depths of Lake Michigan during at least some part of the year and consequently affect many other species in the lake (Smith 1968). In midwinter they are concentrated on the bottom in the deepest portions (Wells 1968). By late winter and early spring they move shoreward into the mid-depth region also occupied by the bloater. During late spring and summer alewives concentrate inshore. In fall, offshore movement to mid-depth regions takes place. Apparently this seasonal migration follows the pattern of annual water temperature changes. Our data can only partially substantiate the observed seasonal pattern, since only inshore regions were sampled. Length-frequency histograms of alewives

TABLE B11. Summary of nonparametric analysis of alewife beach seine data (April - October 1973) from southeastern Lake Michigan. NS = not significant; S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic value	P
Station (A, B, F)	2	0.59356	(.74) NS
Area (Cook, A, B; Dunes F)	1	0.00399	(.95) NS
Month	6	24.5850	.0004 S

caught in standard series nets were compiled by gear type (Figs. B8-10). These histograms have to be viewed in total because of size selectivity of the various gear. Because very few juveniles were collected by our inshore sampling (they reside at mid-depths further out into the lake--Brown 1972), only seasonal distribution of young-of-the-year (YOY) and adults will be discussed below.

Young-of-the-Year. Young-of-the-year were first caught in limited numbers in July through day seining in the Cook Plant vicinity (Fig. B8). Lack of YOY in day seine catches at Warren Dunes may be related to schooling behavior (i.e., patchy distribution) of this species. No YOY were caught by trawling (Fig. B10), indicating these fish probably remain inside the 6.1-m contour, although small size of YOY alewife may have made them less susceptible to trawling. Seined YOY were 20-30 mm and probably hatched 3-4 weeks prior to the date of capture, indicating June to be the month when spawning occurred.

In August, YOY catch increased enormously; conversely catch of adults diminished noticeably. Modal length of YOY was approximately 40 mm. Numbers of YOY caught by day seining were high at all stations. At night YOY apparently moved to deeper water, since few were seined while numerous YOY were caught in trawls at Warren Dunes. Some YOY were caught by day trawling at 6.1 m off Warren Dunes, indicating these fish range out to this depth during the day. Absence of YOY in night trawls at the Cook Plant is puzzling. Young-of-the-year may be following daily temperature changes to a greater extent than adults.

YOY were not caught by seining in September. During sampling, weather conditions were poor and high waves may have made beach-zone conditions adverse for these fish. Trawling, which took place a week later during an upwelling, indicated that limited numbers of YOY were in deep water (6.1 and 9.1 m) during the day but were scarce at night.

By October, YOY were again present in the beach zone. Modal length had increased to about 50-60 mm. This agrees well with 1962-66 and 1970 observations in southeastern Lake Michigan (Brown 1972). It is, however, well below the 80-90 mm average length in 1968-1969. Wells (1968) found average length of young alewife to increase consistently with increasing distance from shore. Thus our estimates of average length may be biased downward. Young-of-the-year utilized the beach zone during the day in October, which may be interpreted as either temperature preference behavior or acquisition of the adult behavioral pattern evidenced in spring. Trawl catch in October showed that YOY were at 6.1 and 9.1 m during the day, but were not present in as great numbers as was found at night.

No YOY were caught by seining in November and December. These fish had apparently left inshore waters with the remaining alewife population, although we could not verify this because trawling was not performed. However, modest numbers of YOY alewife were captured during November 1974 trawling activities, indicating at least part of their numbers were still inshore.

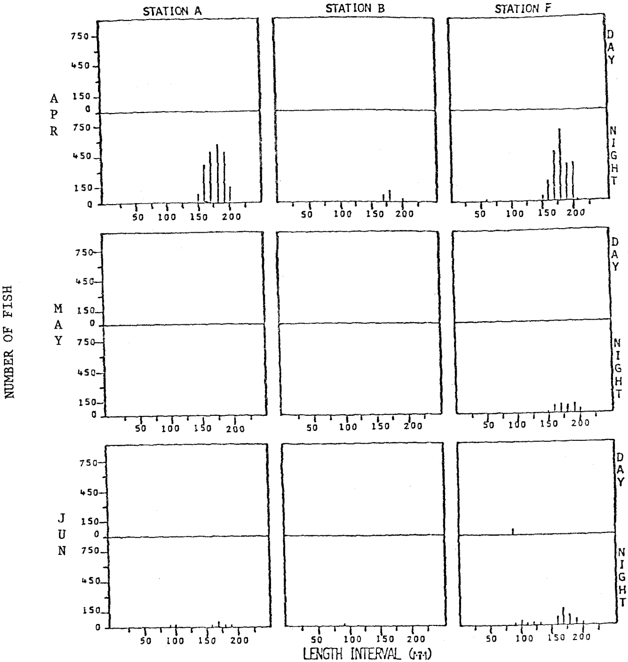


FIG. B8. Length-frequency histograms for alewives caught in standard series seining during 1973 in the Cook Plant study area of southeastern Lake Michigan.

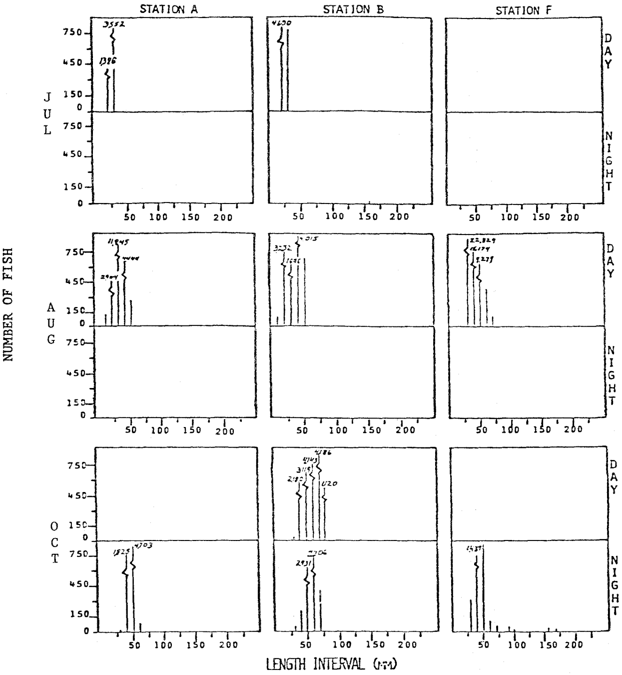


FIG. B8 continued.

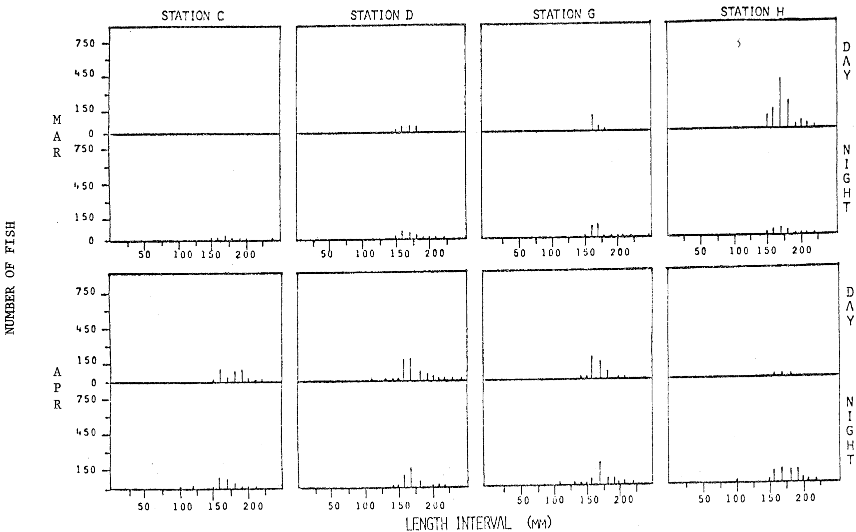


FIG. B9. Length-frequency histograms for alewives caught in standard series gillnetting during 1973 in the Cook Plant study area of southeastern Lake Michigan.

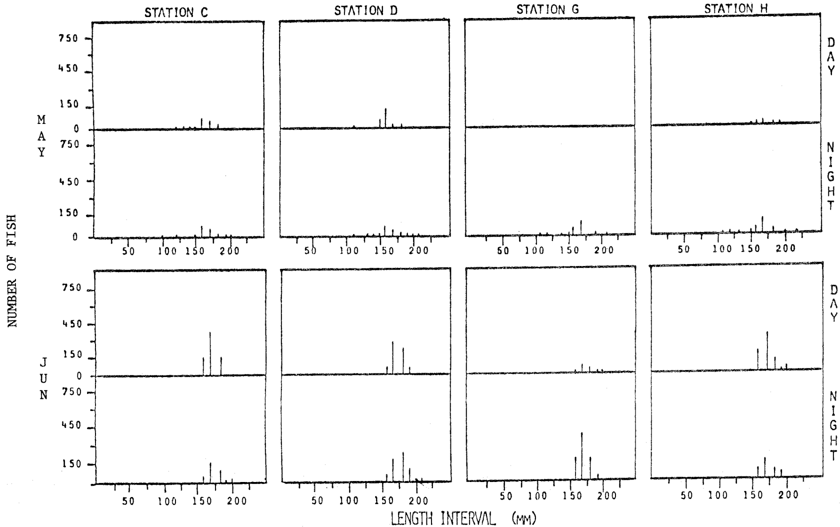


FIG. B9 continued.

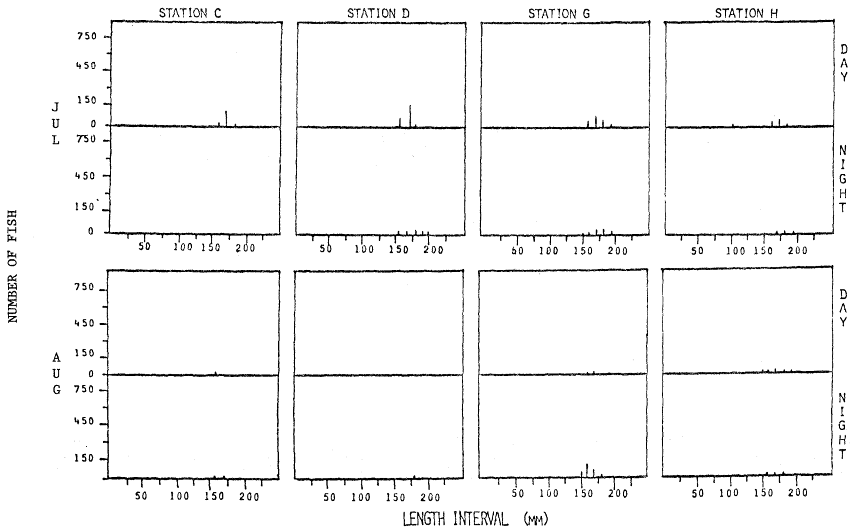


FIG. B9 continued.

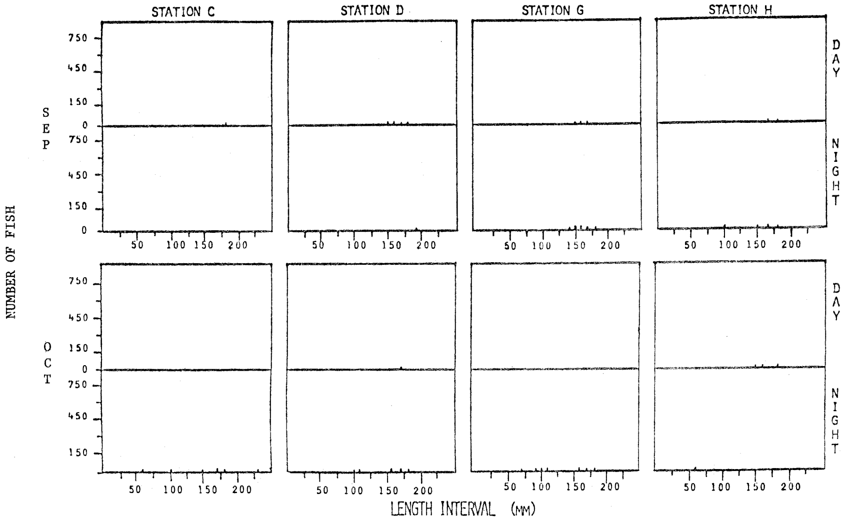


FIG. B9 continued.

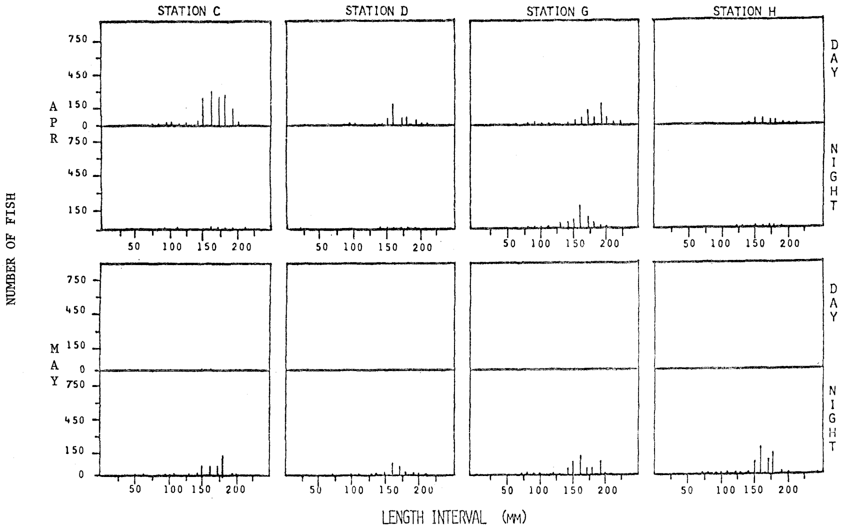


FIG. B10. Length-frequency histograms for alewives caught in standard series trawling during 1973 in the Cook Plant study area of southeastern Lake Michigan (ND = no data).

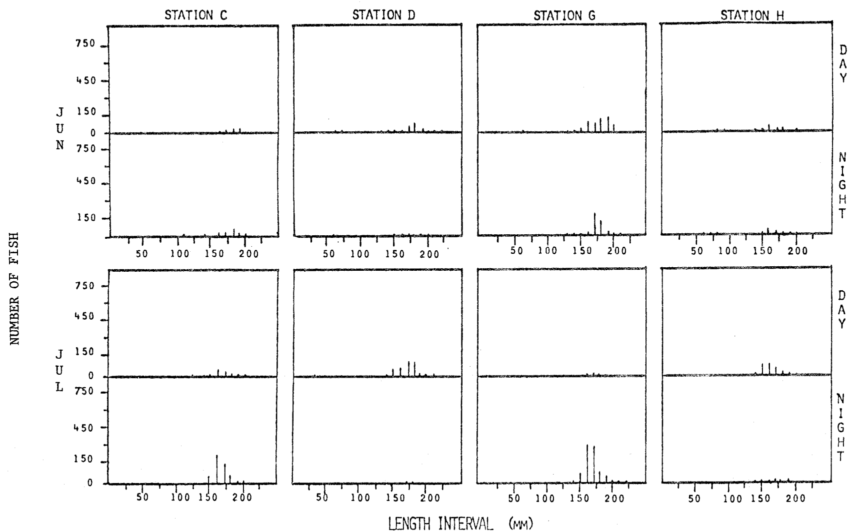


FIG. B10 continued.

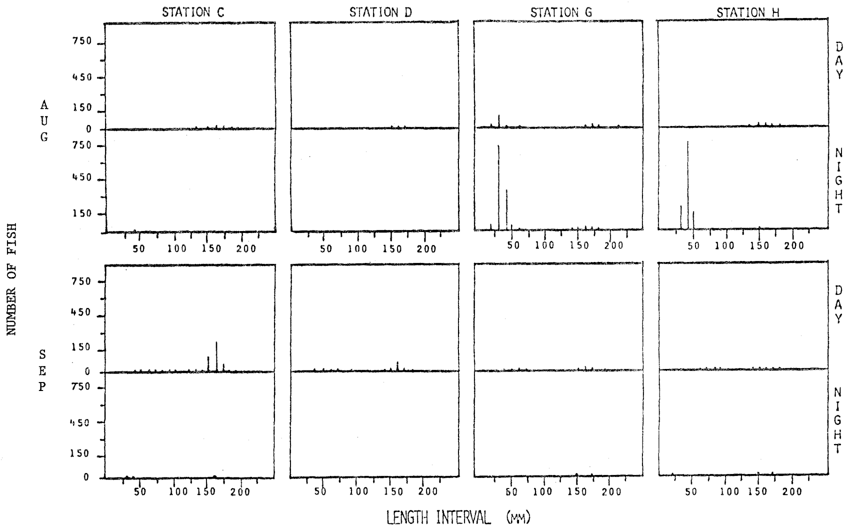


FIG. B10 continued.

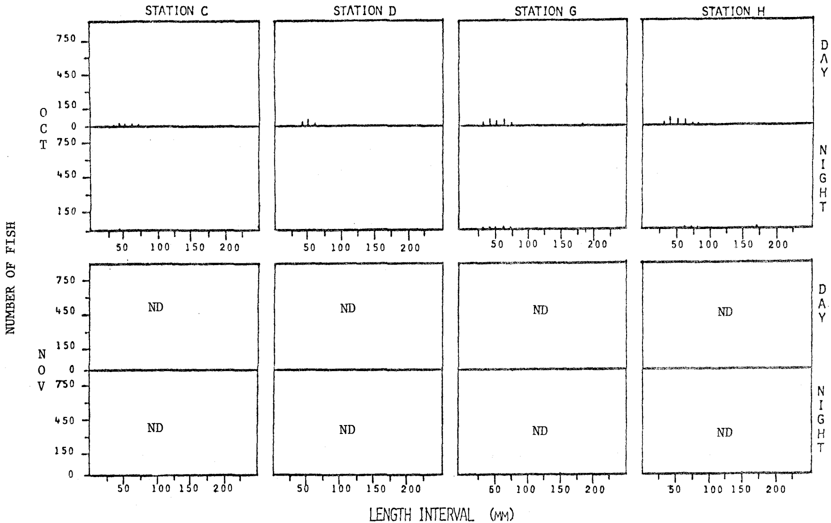


FIG. B10 continued.

YOY apparently move to offshore regions and remain there until reaching full sexual maturity. It is unlikely that they grow enough during winter to be mistaken as adults the following spring. Small numbers of alewives in the 50-100 mm range caught in April, May and June are probably a mixture of small adults due to size segregation and occasional sampling of the fringes of a predominantly pelagic population of 1 and 2-yr old fish located mainly outside the trawling zone (Wells 1968; Brown 1972). More extensive sampling studies (e.g. Brown 1972) have shown that after their first summer alewives are predominantly pelagic remaining primarily at mid-depths until their third summer.

Adults. Adults first moved into our study zones in March. These were large fish in the 140-200 mm range (Fig. B9). Other studies (Rothchild 1965; Wells 1968) also found larger fish leading the inshore migration. By April much more of the adult population had reached the inshore regions. Once again, these were large numbers of individuals in the 150-200 mm range, probably the III, IV and V age groups (Brown 1972; Norden 1967a). Adults were also caught in the beach zone at night in April. The adult population was now exploiting all depths of the inshore waters.

Numbers of adults caught in May decreased, probably a result of warming of inshore waters. As an increasing area of the lake was heated to preferred temperature levels alewives were able to disperse more widely, thus reducing their numbers inshore.

Large numbers of ripe, ripe-running and spent alewives caught in June and July indicate a June-July spawning period (Table B12). Landlocked alewives spawn primarily on shallow beaches (Scott and Crossman 1973) and by migrating up rivers (Edsall 1964; Brown 1972). Further support for a June-July and some of August spawning period is provided by presence of alewife eggs and 1-day old larvae in the area during these months (see Section C). Spawning continued through July but apparently at a diminished rate. Adults captured were still in a length range of 160-200 mm. Slow growth of alewives in Lake Michigan (Smith 1970) makes it difficult to detect any pattern of increasing modal length for adults over a single growing season.

Very few adults were caught by beach seining after June. Evidently they do not return to this area after spawning. Some adults were caught by gillnetting and trawling at 6.1-m and 9.1-m stations after July and into fall, but numbers were low compared to spring and early summer catches. In November only five small alewives (45-63 mm) were caught in beach-zone seining activities, the vast majority of the population having left inshore waters.

Temperature-Catch Relationships

Graham (1956) estimated that alewives acclimated to 10, 15 and 20 C approached their upper incipient lethal temperatures at just above 20 C, just below 22.8 C and about 22.8 C, respectively. On 28 July 1964 Wells

TABLE B12. Monthly gonad conditions of alewives as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	[1]Dec
					Females						
Poorly dev.		50	21	25			1	25	38		
Mod. dev.		97	190	103	2		3	22	1		
Well dev.		12	270	253	224	184	1				
Ripe-running				1	9	2					
Spent					35	21	45	13	5		
					Males						
Poorly dev.		38	20	28	1		11	40	59		2
Mod. dev.		104	267	132	8	1		5	1		1
Well dev.		13	140	165	244	153					4
Ripe-running											
Spent					243	173	74	44	13		
					Unable to distinguish						
		3		1	20	3	19	3	4		1

[1] Includes only impinged fish.

(1968) found most alewives in water temperatures from 11-16 C even though a complete range of temperatures were available spatially to them. Our temperature-catch data for alewives (Fig. B11) indicate to some extent the inshore preference range of adults and YOY. Adults were captured primarily by trawling and gillnets, although many were caught some months in seines. The lower range, 4-12 C, where one peak catch occurred is probably representative of temperatures recorded at the time when adults were captured in spring. Adults appear to prefer the 16-22 C temperature range. Most YOY were caught at 16-20 C and 24-28 C with a probable preference for the upper end of this range.

Other Considerations

Alewives were observed on numerous occasions by SCUBA divers working in the vicinity of the Cook Plant during 1973-1974. Fish were seen both in the riprap area and at control stations north and south of the riprap. Although

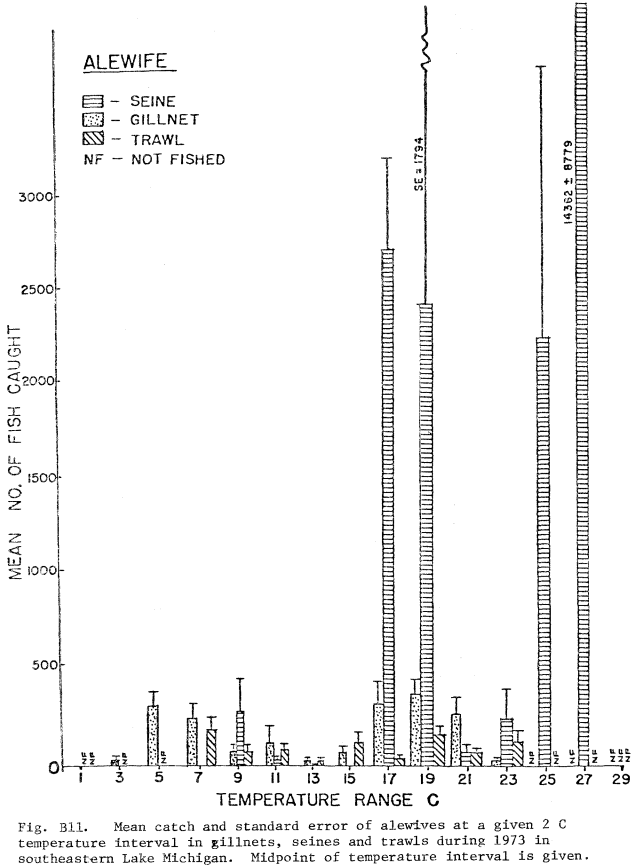


Fig. B11. Mean catch and standard error of alewives at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

on one occasion more than 200 alewives were counted during a night dive in June 1973, counts were usually 10 or less. This low count is surprising in view of the abundance of these fish during the warmer months as indicated by our fishing efforts in the area. It may be that tendency to school (be unevenly distributed) could result in underestimates of numbers of alewives present in an area when determined strictly by visual counts.

Fish were seen both during the day and somewhat more at night. Nocturnal and diurnal activity levels appeared to be similar. Fish were not observed to "rest or sleep," although slow, solitary swimming was more frequently observed at night.

Alewives were seen throughout the water column at night and during the day, with a tendency to congregate around the structure nocturnally. Fish exhibited both solitary and schooling behavior, although schooling was more pronounced among juveniles.

During June and July 1973, divers noted dead alewives on the surface and on the bottom ($1/10\ m^2$). Many dead alewives on the surface and beaches were also noted by field crews during late June and early July of 1973. On 18 June 1973 several hundred dead alewives floating on the surface ($2/10\ m^2$) were observed at both the Cook Plant and Warren Dunes trawling stations. These occurrences appeared to be local population mortalities rather than massive dieoffs.

Spottail Shiner

Spottail shiners are an important forage fish of relatively large lakes and large rivers. Their distribution in North America extends from portions of Canada south to the United States from Georgia in the east to Iowa and Missouri in the west (Scott and Crossman 1973). In Lake Michigan they are abundant in the inshore areas, but few studies have been made on their ecology.

The first study on biology of spottails in Lake Michigan was an investigation of age, growth and food habits done in Little Bay de Noc (Basch 1968). Their seasonal depth distribution in southeastern Lake Michigan as determined by experimental trawling has also been studied (Wells 1968). Recently, some aspects of the life history of spottails from southeastern Lake Michigan, the Kalamazoo River and western Lake Erie have been investigated (Wells and House 1974). Elsewhere, the first studies of spottail shiner biology were based on seine samples from Clear Lake, Iowa (McCann 1959; Griswold 1963). From seine and trawl collections, Smith and Kramer (1964) made an extensive investigation of spottails in Lower Red Lake, Minn. Although a portion of the biology of this species is known, more studies are essential to understanding the importance of this fish's niche in the ecology of the inshore zone of Lake Michigan. This cyprinid was the second most abundant fish in our 1973 collections.

We caught spottails during every month that fish samples were taken (Table B6). The majority of the total catch was taken by seining, with

gillnets and finally trawls representing the next most effective fishing gear. Most spottails caught with the seine were taken during the day, while higher nocturnal catches predominated gillnet and trawl samples.

Statistical Analysis of Spottail Shiner Catch

Trawls. Results of ANOVA for spottail shiner trawl catches (Table B13) showed highly significant ($P < .01$) main effects due to MONTH, DEPTH and TIME of day. All main effects entered into a significant ($P < .01$) third-order interaction (AREA x MONTH x DEPTH x TIME of day) (Fig. B12) and thus are nonadditive. This in turn confounds interpretation of main effects. Of course much of the variability that contributes to the significance of this interaction is inherent to both the trawling method and moderate schooling behavior by spottails. Another factor, the variability of which contributes to the significance of these interactions, is the different temperature regimes encountered between areas during sampling. In particular, an upwelling on 21 August 1973 dropped bottom temperature at the Cook Plant to 8.5 C, while on the same day fishing temperatures at Warren Dunes averaged 14.1 C. Trawling data on that day indicated distinct differences in spottail abundance with much higher catches recorded at Warren Dunes than at the Cook Plant. Moderate temperature differences during other periods may have influenced catches similarly (refer to Seibel and Ayers 1974 for a more detailed discussion of upwellings in the study area). In another example, greater numbers of spottails were caught at the Cook Plant than at Warren Dunes in July, while in August this pattern was reversed, with higher day catches at Warren Dunes. Differences in catch between these areas can be partially attributed to thermal conditions.

It is probably safe to assume most of the third-order interaction is caused by two distinct but overlapping activity patterns. The first of these is the general shoreward migration of adult spottails which begins in spring. In June and July adults remain near the beach zone inside the 6.1-m contour, thus out of the trawling depth. By late summer they again move to deeper waters.

The second activity pattern concerns diel migrations. High night catches at 6.1 m in spring and fall indicate that during these periods larger adults are active (probably extending their foraging range) beyond the seining area. Low day and night trawl catches in June and July suggest that spottails are distributed inshore from the 6.1-m contour, probably corresponding to spawning activity near the beach. Gonad data for 1973 (Table B14) and sled tows for larvae in 1974 support this June-July spawning hypothesis.

Support or the confirmation of these activity patterns as explanations for observed interactions must await at least another year of preoperational data. Further insight into the biology of spottail shiners may be obtained by briefly examining the three significant ($P < 0.01$) first-order interactions.

The MONTH x AREA interaction (Fig. B13) suggests that during August

TABLE B13. Summary of analysis of variance for spottail shiners caught in trawls in the Cook Plant study areas from April through October 1973.

Source of variation	df	Adjusted mean square[1]	F-Statistic	P
AREA	1	.19208	3.07	NS[2]
MONTH	6	1.58934	25.44	<.01
DEPTH	1	4.06396	65.04	<.01
TIME of day	1	2.00799	32.14	<.01
AxM	6	.85194	13.64	<.01
AxD	1	.27013	4.32	<.05[3]
AxT	1	.41948	6.71	<.05
MxD	6	.29358	4.70	<.01
MxT	6	2.40216	38.45	<.01
DxT	1	3.38200	54.13	<.01
AxMxD	6	.13098	2.10	NS
AxMxT	6	.15636	2.50	<.05
AxDxT	1	.02600	.42	NS
MxDxT	6	.37864	6.06	<.01
AxMxDxT	6	.28062	4.49	<.01
Within cell error	54[4]	.06238182		

1 Mean squares were multiplied by harmonic cell size/maximum cell size (n_h/N = .966) to correct for 2 missing observations where the cell mean was substituted.

2 Not significant (P <.05).

3 Not significant (.01 <P <.05).

4 Two degrees of freedom were subtracted to correct for 2 missing observations where the cell mean was substituted.

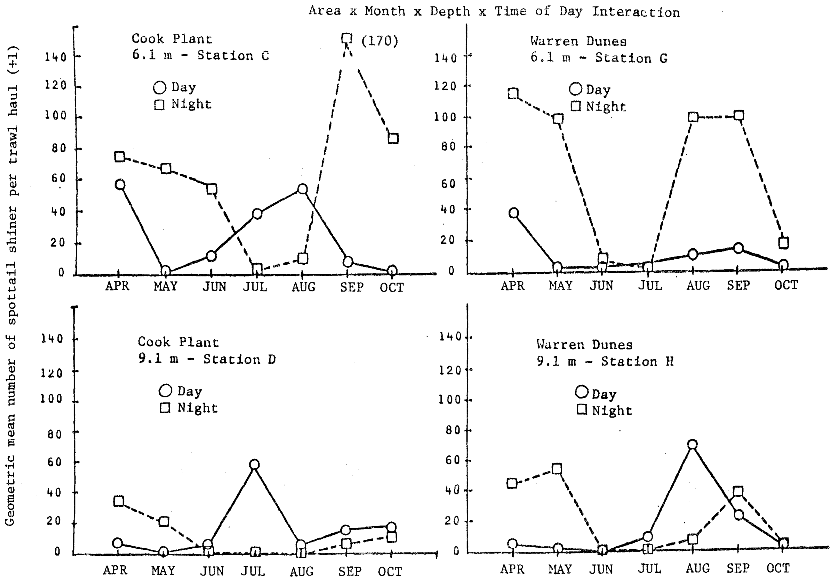


FIG. B12. Geometric mean number of spottail shiners caught in duplicate trawl hauls during the day and night, April through October 1973, at the Cook Plant and Warren Dunes, southeastern Lake Michigan.

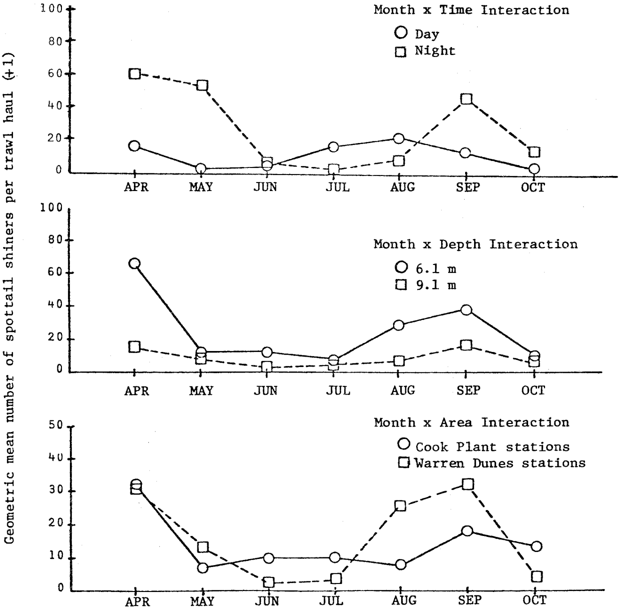


FIG. B13. Geometric mean number of spottail shiners caught in duplicate trawl hauls during the day and night (stations and depths pooled), at 6.1 m and 9.1 m (areas and time of day pooled) and at the Cook Plant and Warren Dunes (depths and time of day pooled). Trawling was done April through October 1973 in southeastern Lake Michigan.

TABLE B14. Monthly gonad conditions of spottail shiners as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	[1]Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.	6	14	7	4			3	55	52	5	
Mod. dev.	20	129	122	37	2		4	22	6	18	
Well dev.		7	159	355	273	46	1				
Ripe-running				1	3	2					
Spent					67	109	152	76	3		
					Males						
Poorly dev.	13	38	16	5	1			16	112	4	1
Mod. dev.	2	34	92	95	7		2	7	41	4	
Well dev.		1	30	54	11	10	1		1		
Ripe-running											
Spent					51	50	77	22	6		
					Unable to distinguish						
				8	32	20	105	27	34		

[1] One female with moderately developed gonads was impinged in January.

and September spottails were more abundant off Warren Dunes than the Cook Plant, in other months numbers at the two areas were similar. As previously discussed, thermal differences between Warren Dunes and Cook in September may have significantly affected catches at the two areas. The MONTH x DEPTH interaction (Fig. B13) suggests that in April, August and September spottails concentrated more at 6.1 than at 9.1 m, while during May, June, July and October there was no distinct preference for either depth. Similarly, the MONTH x TIME interaction (Fig. B13) shows significant changes in diel behavior, with nocturnal activity predominant in spring and fall and diurnal activity predominant in summer.

Gillnets. Patterns of gillnet catches reflect movements of adult spottails (Fig. B14). During March and April, before these fish had migrated extensively into the beach zone, gillnets caught more spottails than either seines or trawls. Larger adults apparently led the population into inshore waters in spring. The very low July catch in both study areas corroborates trawling evidence which showed most adult spottails had moved to the beach zone.

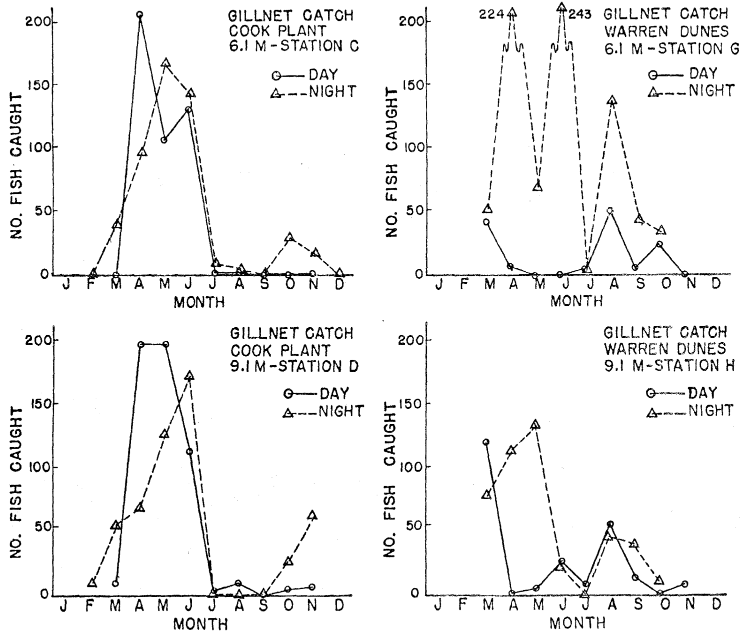


FIG. B14. Mean number of spottail shiners caught in gillnets set during day and night once per month February through December 1973 in southeastern Lake Michigan.

As was seen in the trawl catch, night yields from gillnets were generally higher than day catches for both areas. However, while trawl catches showed a change to higher day catches in July and August followed by higher night catches in September and October, no such pattern was evident in gillnet catches. In November and December catches were low, but some spottails were still present in the area. Comparisons between day and night activity derived from gillnet data must be tempered by evidence that spottails feed just before sundown (Griswold 1963). Setting of the day-night gillnets probably overlaps this peak activity period which would tend to diminish validity of inferences. Consequently no statistical tests were performed to test for differences in catch between day and night.

The only apparent difference between the Cook Plant and Warren Dunes areas occurred in August and September when Warren Dunes had consistently higher day and night catches at both depths. These apparent area differences, when tested by non-parametric statistics (Table B15), were not significant. In addition, neither non-parametric test used indicated significant differences between depths. Of course, differences in catch among months were highly significant (P = .008).

Seines. In terms of spottails caught, seines were by far the most productive gear. Most seined fish were captured during the day, although the general pattern was high night catches in April and May and high day catches in June and August (Fig. B15). Other studies have shown that spottail shiners are more easily caught by night seining (Scott and Crossman 1973).

The Kruskal-Wallis test (Table B16) showed no significant differences among the three stations nor between the two study areas. Apparently spottails are uniformly distributed in the beach zones of the two study areas, demonstrating the homogeneous quality of the southeastern Lake Michigan beach zone. As expected, there were highly significant ($P < 0.001$) effects related to seasonal changes. Temporal changes in spottail distribution will be discussed below.

TABLE B15. Summary of nonparametric analyses of spottail shiners caught in standard series gillnets in Cook Plant study areas from April through October 1973. NS = not significant, S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic		Mann-Whitney U statistic	
		Value	P	Value	P
Month (Apr-Oct)	6	17.319	.0082 S	----	----
Depth (6.1 m, 9.1 m)	1	.021363	.8838 NS	669.0	.8837 NS
Area (Cook Plant, Warren Dunes)	1	.029845	.8628 NS	628.5	.8627 NS

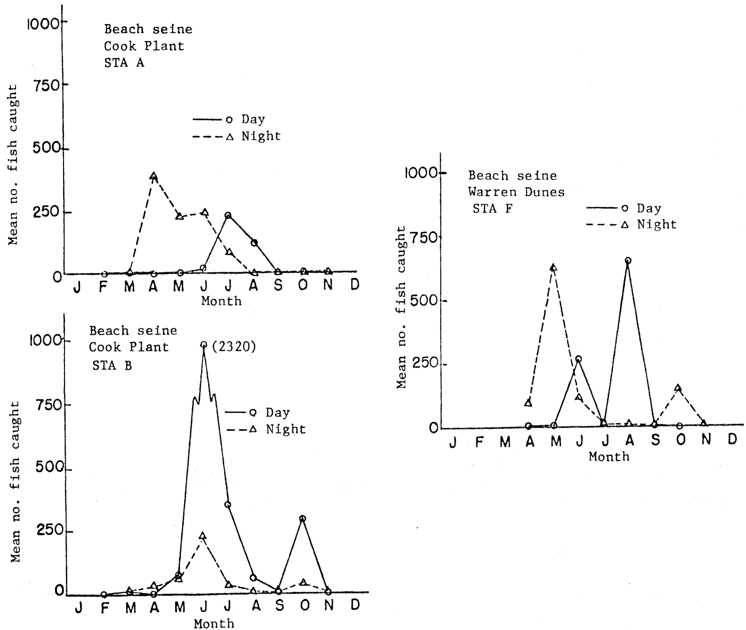


FIG. B15. Mean number of spottail shiners caught in seines fished during day and night once per month February through November 1973 in southeastern Lake Michigan.

TABLE B16. Summary of nonparametric analysis of spottail shiners caught in standard series beach seines in Cook Plant study areas from April through October 1973. NS = not significant, S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic	
		Value	P
Station (A,B,F)	2	1.4899	.4747 NS
Area (Cook A,B, Dunes F)	1	0.2596	.9612 NS
Month (Apr-Oct)	6	26.208	.0002 S

Seasonal Distribution by Age-Size Class

Length-frequency histograms of spottails caught in standard series nets were compiled by gear type (Figs. B16-18). These histograms have to be viewed in total because of size selectivity of the various gear. The following discussion will consider three life stages (young-of-the-year, juvenile and adult) which, because of size variability with age, overlap to some extent. Therefore only major temporal and spatial distributions are discussed.

Young-of-the-Year. Young-of-the-year (YOY), 20-30 mm, first appeared in beach seines in July (Fig. B16). This observation lends further support to the proposed mid-June to early July spawning period in southeastern Lake Michigan. June-July spawning was also found in northern Lake Michigan (Basch 1968) and in Lake Erie (Fish 1932; Wells and House 1974). Scarcity of spottail larvae in any of our plankton net tows during 1973 was probably related to demersal behavior by larvae and our failure to adequately sample this stratum. Numerous spottail larvae have been found in bottom sled tow samples taken in 1974.

By August, YOY were 30-50 mm with a modal length of 40 mm (Fig. B16). This interval increased to 30-60 mm in September and was 20-70 mm by October. The October interval corresponds roughly to the size range of yearlings captured in April (Fig. B18). The broad size range of YOY indicates a prolonged spawning period of at least 2 months. YOY were caught almost exclusively in the beach zone during the day. Considering numbers caught in September and October night trawls, it appears that larger YOY are either moving to deeper water at night and inshore during the day, or many YOY have joined the offshore population of juveniles and adults.

Absence of spottail YOY in September beach seines was probably caused by high wind and waves encountered during sampling, as large numbers of YOY were still present in October beach seines. Turbulence on the beach from high waves forces smaller fish to deeper water.

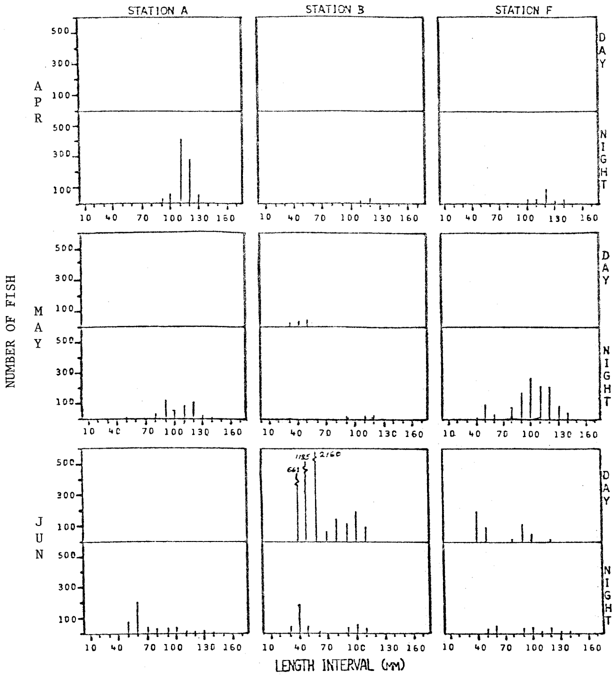


FIG. B16. Length-frequency histograms for spottail shiners caught in standard series seining during 1973 in the Cook Plant study area of southeastern Lake Michigan.

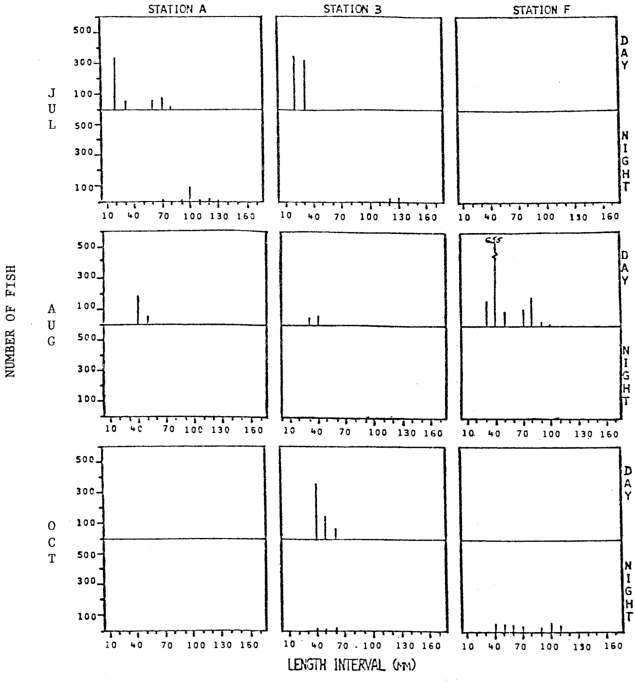


FIG. B16 continued.

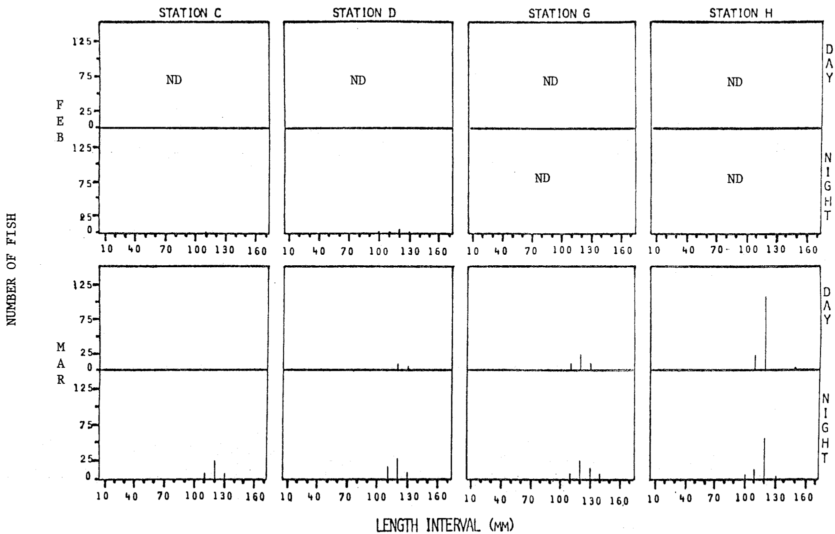


FIG. B17. Length-frequency histograms for spottail shiners caught in standard series gillnetting during 1973 in the Cook Plant study area of southeastern Lake Michigan (ND = no data).

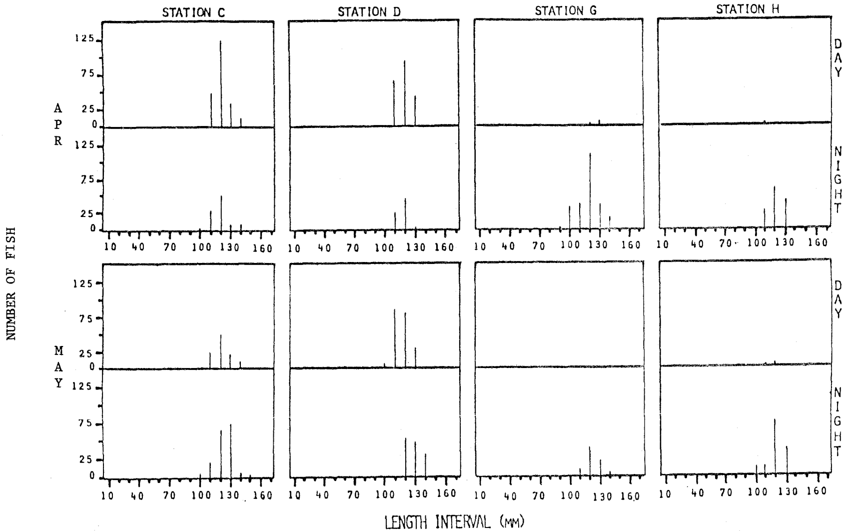


FIG. B17 continued.

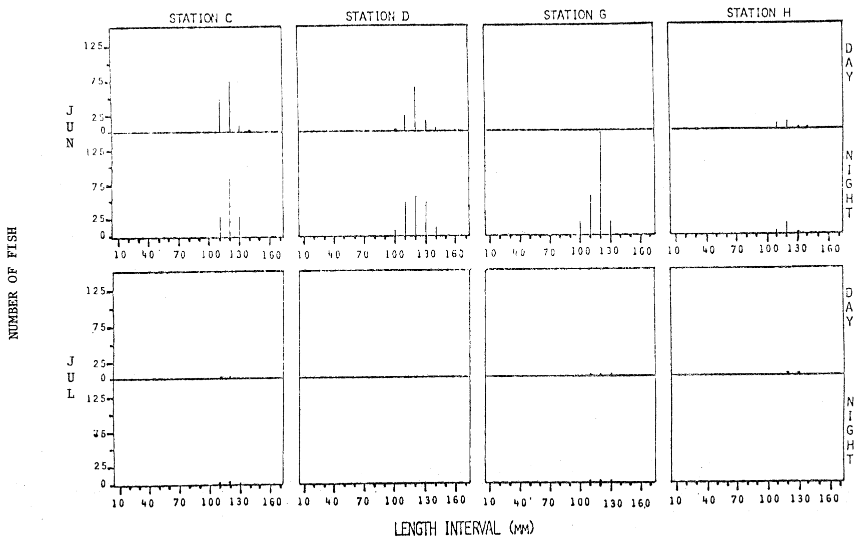


FIG. B17 continued.

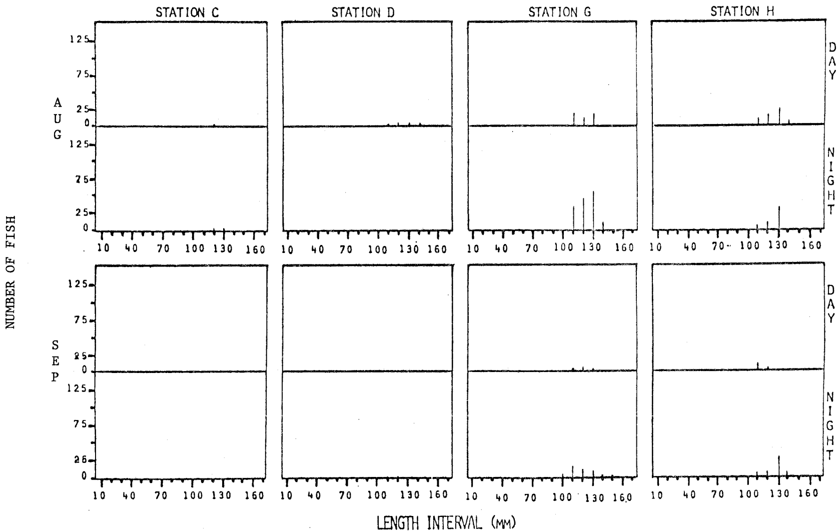


FIG. B17 continued.

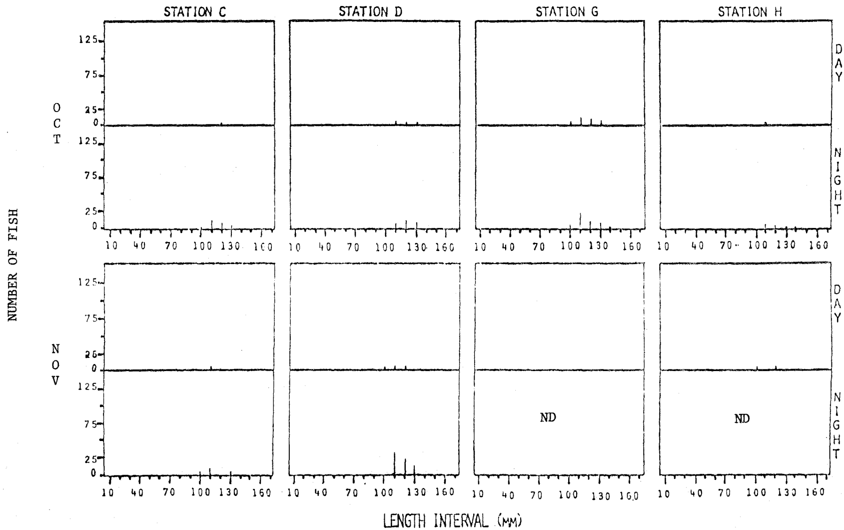


FIG. B17 continued.

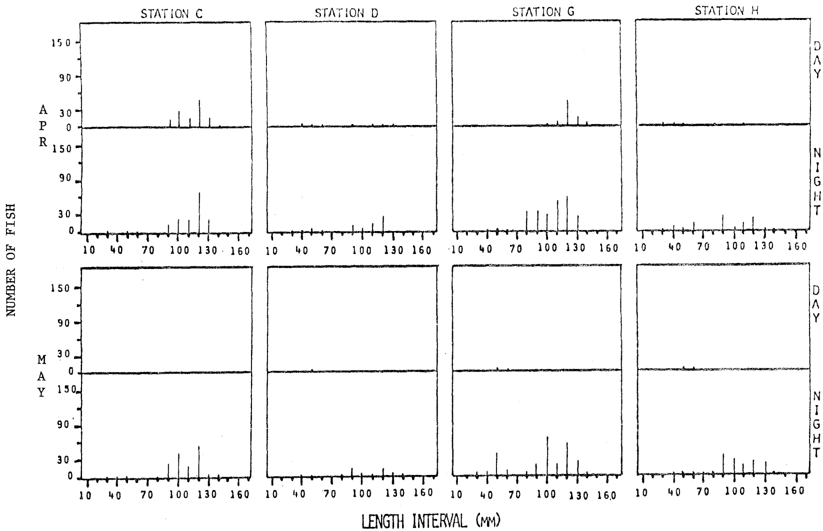


FIG. B18. Length-frequency histograms for spottail shiners caught in standard series trawling during 1973 in the Cook Plant study area of southeastern Lake Michigan (ND = no data).

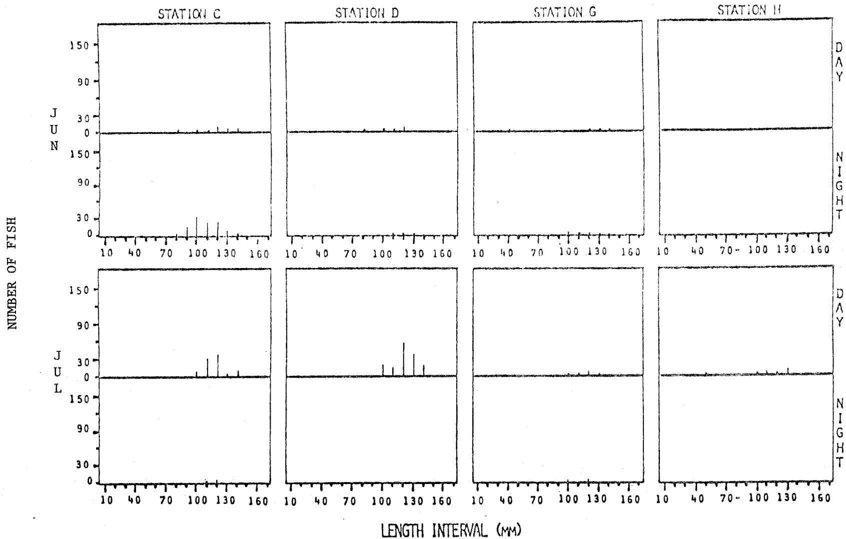


FIG. B18 continued.

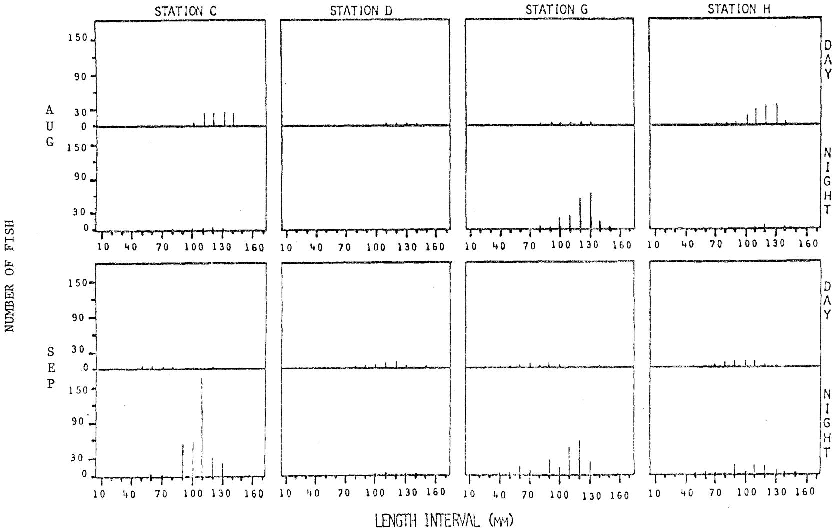


FIG. B18 continued.

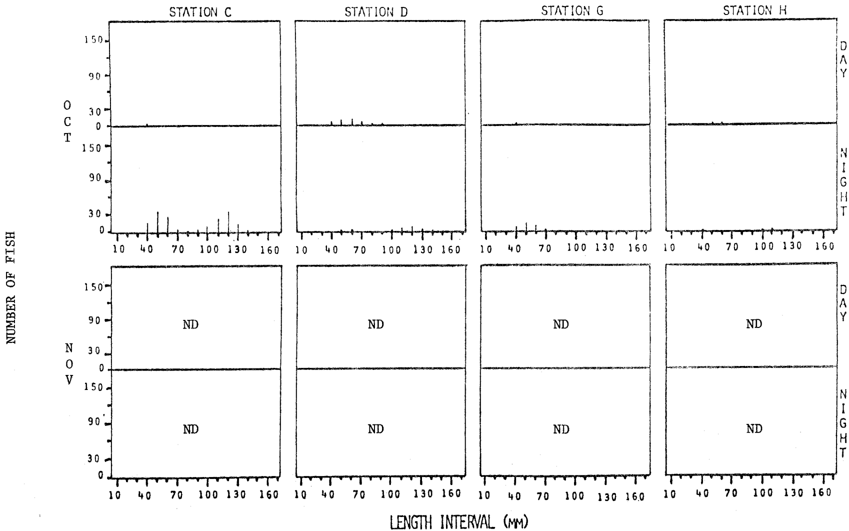


FIG. B18 continued.

Based upon a literature search, our YOY appear to grow noticeably slower than in other studies (Table B17). Average length of YOY in this study was about 50 mm, while in other studies lengths ranged from 54 mm (Wells and House 1974) to 77 mm (Griswold 1963). At the end of their second season of growth our fish approximate the size of those found in other habitats. Our spottails then grow to average lengths that are probably greater than reported elsewhere.

We would expect our spottails to grow at least as fast as those in other habitats, since food appears to be abundant and water temperatures are high. Slower growth in early stages of development and increased growth later in life, growth compensation, may be linked to two interacting factors. First, the large sizes that our fish attain are probably related to absence of predation by larger salmonids. We found very few spottails in stomach contents of larger salmonids. Some documented predators of spottail shiners such as walleye (Smith and Kramer 1964) are rare in the study area. Prominent piscivorous salmonids may ignore spottail shiners in preference for other prey, particularly alewife. Wells and House (1974) have speculated that spottails are not important forage fishes in Lake Michigan.

Factors causing decreased growth of YOY are less clear. Niche overlap with the alewife is suggested as the major factor. In an extensive study of stomach contents of more than 100 spottails from Lower Red Lake, Minn., Smith and Kramer (1974) noted a distinct change in food preference with increasing length. Crustacea, particularly cladocerans and copepods, were major items in diets of spottails between 7 and 69 mm in length. Beyond this size range, insects comprised the bulk of stomach contents. In this study, concentrations of YOY alewife and spottails in the beach zone, both of which are selectively feeding on zooplankton, indicate at least a partial niche overlap. Later, when spottails begin to feed more on benthic organisms, the competitive inhibition from alewives is mitigated and spottails grow at a faster rate. Basch (1968) found that adult spottails and adult alewives did not compete for food in Little Bay de Noc, Mich. Of course, these hypotheses must await analysis of stomach samples.

Juveniles. Juveniles 1-yr old were caught in April along with adults. Throughout our sampling, they appeared to associate with adults in their spatial and temporal ranging. "Juvenile" is a somewhat arbitrary classification for spottails because some fish mature at 1 yr old. Wells and House (1974) found in Lake Michigan 53% of the males and 40% of the females of age I, and all fish of age II were mature (adults). Some juveniles utilized the beach zone along with YOY in August, but for the most part the majority were found offshore with adults. In April, juveniles were 30-70 mm, approximately the same length as YOY captured in October. By July, spottail juveniles were 40-80 mm and in August this range had increased to 90 mm. A few spottails which may have been yearlings in the 100-mm size range were caught in September trawls and gillnets. Annual growth appears to be complete by September. Wells and House (1974) speculated that all age groups had stopped growing by mid-October in southeastern Lake Michigan during 1964.

TABLE B17. Summary of calculated total length in millimeters at each annulus of spottail shiners at various ages. Data are from several habitats. F = female, M = male.

Source	Age class I F	I M	II F	II M	III F	III M	IV F	IV M	V F	V M
McCann 1959 (Clear L., Iowa)	77[1]		98		108					
Smith & Kramer 1964 (Lower Red L., Minn.)	58	56	90	85	106	100	113	103		
Basch 1968 (Northern L. Mich.)	59	57	87	86	105	106	117			
Wells & House 1974[2] (Southeastern L. Mich.)	63	62	97	95	114	108	123	117	131	129
(Kalamazoo River, Mich.)	56	54	80	79	94	93	105	106		

[1] Sexes combined.
[2] Length at the end of each year of life.

Adults. Adults were caught throughout the entire sampling period. The first significant occurrence of adults was in March, primarily at the 9.1-m contour (Fig. B17). Apparently larger adults lead the inshore migration. Size range was from 80-140 mm with an average length of 120 mm. These fish were probably 3-5 yr old, although very few spottail shiners have been found to live more than 4 yr (Carlander 1969). A 120-mm average is similar to the averages calculated by House and Wells (1974) for 4-yr olds (at the end of their fourth year) found in southeastern Lake Michigan (Table B17). Four-year olds averaged 108 mm for males and 114 mm for females in Lower Red Lake (Smith and Kramer 1964), but this may have been the result of gear selectivity--only seines and trawls were used. Basch (1968) reported 4-yr old females averaged 117 mm, which agrees reasonably well with our data. Our longest spottail was a 150-mm female, which is slightly larger than has been reported elsewhere (Trautman 1957; Scott and Crossman 1973).

Adults remained abundant in the study area through June. Gonad examinations (Table B14) indicated that spawning occurred in June and early July. Our SCUBA divers observed spottail shiners spawning on the intake cribs on 17 June 1973. They saw 500-1000 spottails swimming above and into patches of 1 1/2-in thick *Cladophora*. Many of the fish appeared swollen, and when captured and squeezed they exuded eggs and milt. Several females were observed to deposit eggs into the *Cladophora* but subsequent fertilization by males was not observed. In dives on 13 and 26 June spottail shiner

eggs were collected and reared. From this it was concluded that 1) spottails will use *Cladophora* as a spawning substrate to which eggs are firmly attached, and 2) the spawning period may be 3-4 weeks with a noticeable peak occurring in a matter of days. Spawning for an entire population may possibly occur in as short a period as 1 day. In a study on Nemeiben Lake, Saskatchewan, all spottails caught before 10 July were ripe while all those caught after 11 July were spent (Peer 1966). Spawning generally takes place over sandy shoals (Scott and Crossman 1973). After spawning, adults in our study areas began to disperse from the beach zone and into deeper, offshore water (6.1 and 9.1 m). Large numbers of specimens were caught at night in September in trawls, indicating that spottails occupied the same zone in fall as was found in spring.

During the coldest months (November, December, January and February) spottails were present in the inshore waters, but numbers caught were low. We believe spottails were present in the inshore waters at the 6.1-m and 9.1-m contours during this period, but a combination of factors caused low catches. Only gillnetting and seining were performed during some of these months. With water temperatures between 0 and 10 C fish movements are at a minimum, and gillnets are ineffective when fish do not move. Apparently spottails do not enter the beach zone during the colder months, since seining produced few fish. Undoubtedly trawling during colder months would have produced more spottails from the 6.1-m and 9.1-m depths. Trawl catches from southeastern Lake Michigan during November and February indicated that spottails were present in low numbers at 6.1 and 9.1 m and out to 31 m (Wells 1968).

Temperature-Catch Relationships

Wells (1968) found maximum concentration of spottails on 28 July 1964 to be at 16-22 C. Our temperature-catch data also (Fig. B19) indicate to some extent temperatures selected by spottails. There appear to be two peaks of maximum, catch one between 6-12 C and the other at 16-22 C. Apparently during cooler seasons, spring and fall, fish utilize the warmer waters, which probably accounts for the 6-12 C peak. In summer, spottails were caught most often in 16-22 C tempetatures. YOY, which were caught primarily by seining, apparently preferred the warmest temperatures, up to 28 C in summer.

Other Considerations

During examinations of spottails caught in 1973, a diseased condition on some fish was noted. Approximately 50-100 fish were found to have an infection of the abdomen. This infection is being analyzed by fish disease specialists and will be reported, with incidence numbers, in the 1974 fish report. Incidence of this disease suggests that spottails may be reaching a population peak in the study area. Future computing refinements of disease incidence plus computation of condition factors and length-weight regression may lend support to this theory. A possible population decline could result if this disease increases in future years.

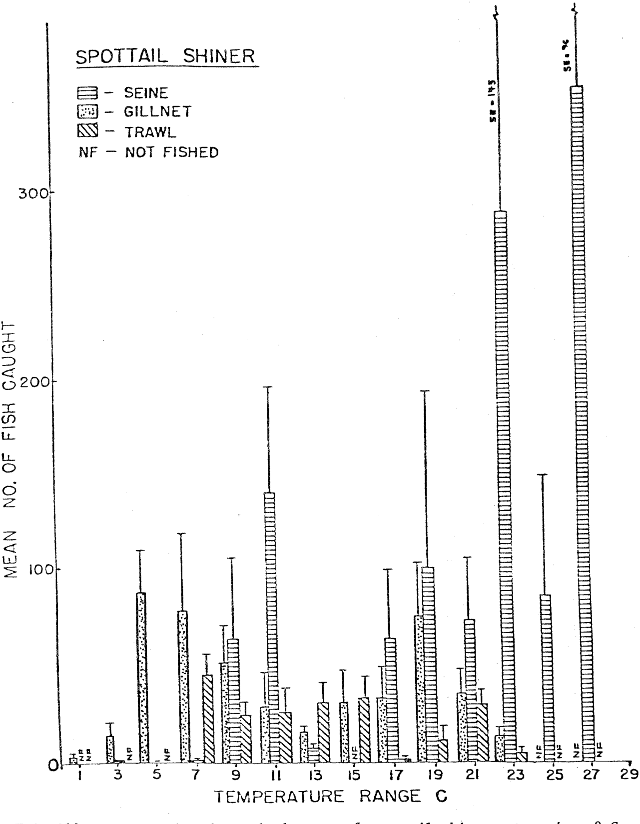


FIG. B19. Mean catch and standard error of spottail shiners at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

Population declines caused by disease are not uncommon. The dramatic die-off of smelt in the early forties was attributed to a bacterial or viral infection (Van Oosten 1947).

Rainbow Smelt

Rainbow smelt is an introduced marine species in Lake Michigan. The present population originated from an initial planting in Crystal Lake, Mich., in 1912 (Van Oosten 1937) and entered Lake Michigan via a small drainage stream about 1922 (MacCallum and Regier 1970). They spread rapidly after entering the lake; the first catch of smelt in commercial nets occurred near Frankfort, Mich. in 1923. By 1924 these fish had entered Green Bay and by 1936 had occupied the entire lake (Wells and McLain 1973). Commercial catch of smelt rose steadily from 3.9×10^4 kg (8.6×10^4 lb) in 1931 to 2.2×10^6 kg (4.8×10^6 lb) in 1941. The smelt population suffered a catastrophic collapse in winter 1943, such that by 1944 production of smelt was only 2.3×10^3 kg (5×10^3 lb). Apparently these smelt died of a viral infection (Van Oosten 1947). The population rebounded quickly, however, and commercial yield peaked in 1958 with a 4.1×10^6 kg (9.1×10^6 lb) catch. Since that time, production has been largely determined by market demand. In addition to commercial fishing, sport fishing by dipnetting in streams and beach areas has been a sizable recreational activity in Michigan every spring (Wells and McLain 1973).

Smelt are preyed upon by a variety of creatures--lake trout, landlocked salmon, brook trout, burbot, walleye, perch, gulls, crows and their own species (Scott and Crossman 1973). In Lake Michigan, smelt have been found to be an important item in the diet of lake trout (Wright 1968), but in the Cook Plant area we have found that alewife are by far the most important forage fish for larger salmonids, at least in the inshore zone.

Statistical Analysis of Smelt Catch

Trawls. Results of the analysis of variance (ANOVA) (Table B18) for trawl catches showed highly significant ($P < .01$) main effects due to MONTH, DEPTH and TIME of day; no significant differences were detected between study areas. There were four significant first-order interactions which confounded interpretation of main effects. Before considering these interactions in detail (Fig. B20), the biological phenomena underlying the results of ANOVA should be considered. In particular, the spatial and temporal uses of the inshore zone, in this case 9.1 m, by smelt are particularly relevant. Adult and yearling smelt are normally found in the inshore zone only during the spring spawning run. Smelt may also follow the cold-water mass of upwellings inshore; during summer months, however, upwellings and the subsequent presence of smelt inshore are essentially brief and randomly occurring events. Following spawning or as inshore water temperatures rise, adult smelt return to deeper, cooler offshore waters of the lake. Smelt larvae remain too small to be captured in our trawl mesh until August, at which time they are caught in abundance. Thus two factors, spring spawning and late summer recruitment of YOY, account for much of the significance of the interactions.

TABLE B18. Summary of analysis of variance for smelt caught in trawls in the Cook Plant study areas from April through October 1973.

Source of variation	df	Adjusted mean squares[1]	F-statistic	P
AREA	1	0.34881	4.39	<.05[2]
MONTH	6	4.42583	55.68	<.01
DEPTH	1	5.88228	74.00	<.01
TIME of day	1	1.25386	15.77	<.01
AxM	6	1.15233	14.50	<.01
AxD	1	0.80302	10.10	<.01
AxT	1	0.02334	0.29	NS[3]
MxD	6	1.56289	19.66	<.01
MxT	6	1.39539	17.55	<.01
DxT	1	0.28181	3.55	NS
AxMxD	6	0.10304	1.30	NS
AxMxT	6	0.24387	3.07	<.05
AxDxT	1	0.00166	0.02	NS
MxDxT	6	0.12616	1.59	NS
AxMxDxT	6	0.24557	3.09	<.05
Within cell error	54[4]	0.0794938		

1 Mean squares were multiplied by harmonic mean cell size/maximum cell size ($n_h/N = 0.966$) to correct for two missing observations where the cell mean was substituted.

2 Not significant (.01 < P < .05).

3 Not significant (P > .05).

4 Two degrees of freedom were subtracted to correct for two missing observations where the cell mean was substituted.

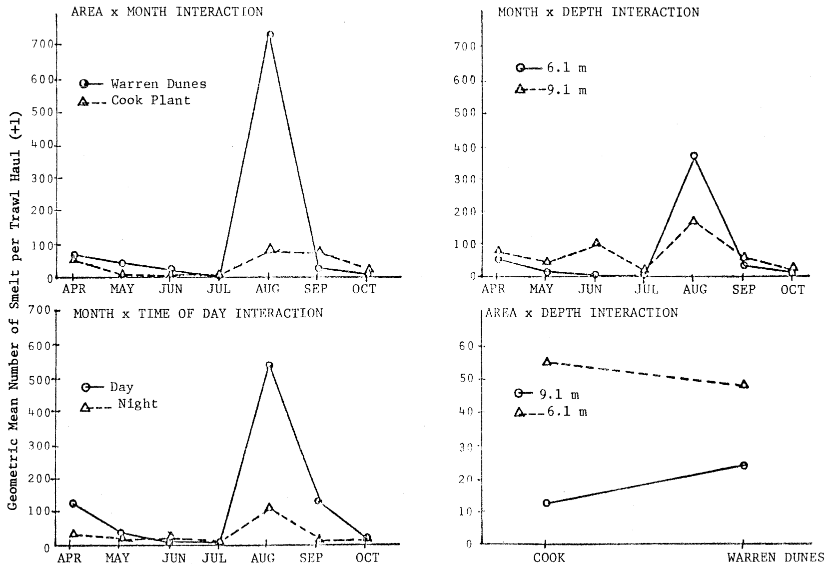


FIG. B20. Geometric mean number of smelt caught in duplicate trawl hauls at the Cook Plant and Warren Dunes (depth and time of day pooled by month), at 6.1 and 9.1 m (areas and time of day pooled by month), during the day and night (areas and depths pooled by month) and at 6.1 and 9.1 m (time of day and month pooled over area) in southeastern Lake Michigan in 1973.

The MONTH x TIME of day interaction (Fig. B20) illustrates the above two factors and also lends supporting evidence to a hypothesized diel vertical migration of YOY (our Section C; Ferguson 1965). If such a migration occurs one would expect higher densities of YOY smelt in trawling zones during the day. Trawling in August and September when YOY are first recruited confirmed this pattern, with far greater day catches at all stations. Higher diurnal abundance of smelt, mostly adults, in April may indicate a similar behavior pattern but may also be related to nocturnal migration of spawning adults to the beach zone.

The MONTH x DEPTH interaction (Fig. B20) is related to high recruitment of YOY at 6.1 m in August. These catches at 6.1 m are apparently related to the temperature preference and schooling characteristics of YOY smelt. First of all, preliminary analysis of extensive larvae sled tow samples taken in August 1974 has shown that YOY are more concentrated at 9.1 m (colder water) than at 6.1 m. This contradicts the observed 1973 pattern which was characterized by an upwelling during sampling in August. This upwelling may have extended cool hypolimnionic waters inshore and also the range of smelt. Moreover since smelt have a greater tendency to school when temperatures are warmer (Ferguson 1965) and since clustering in mobile animal populations can introduce wide variations among samples (Taylor 1953), one would expect wider variation among stations if thermal differences were present. There was up to 7 C temperature differential among trawl samples taken during August. However, the high August catch may simply be an anomaly indicative of high variability within the system.

AREA enters into two significant first-order interactions with MONTH and DEPTH. The first of these (AREA x MONTH) is almost entirely related to very high catches of YOY at Warren Dunes in August (Fig. B20). The large difference in geometric mean abundance suggests that physical factors between study areas differ, with Warren Dunes being the more suitable habitat--an unproven hypothesis. The effect may also be the result of temperature differentials between study areas, as an upwelling was in progress during part of the trawling period.

The AREA x DEPTH interaction (Fig. B20) is mainly due to smelt being more abundant at 9.1 m at Cook Plant than at Warren Dunes, while conversely at 6.1 m smelt were more abundant at Warren Dunes than at the Cook Plant. No explanation other than possible physical differences can be given.

Gillnets. Gillnet catches are biased in that they capture only actively moving fish and primarily adult smelt. The majority of our total smelt catch (all gear) consisted of YOY, yearlings and a few adults. Nonparametric analysis (Table B19) showed no significant differences between either areas or depths.

In March, the first month of gillnetting, modest numbers of smelt were captured--10 at all stations combined except 9.1 m Warren Dunes where 65 were caught (Fig. B21). Most of these fish were entering the inshore area from deeper water in preparation for spawning. April 6.1-m catches were the highest of any month, indicating the fish were ranging

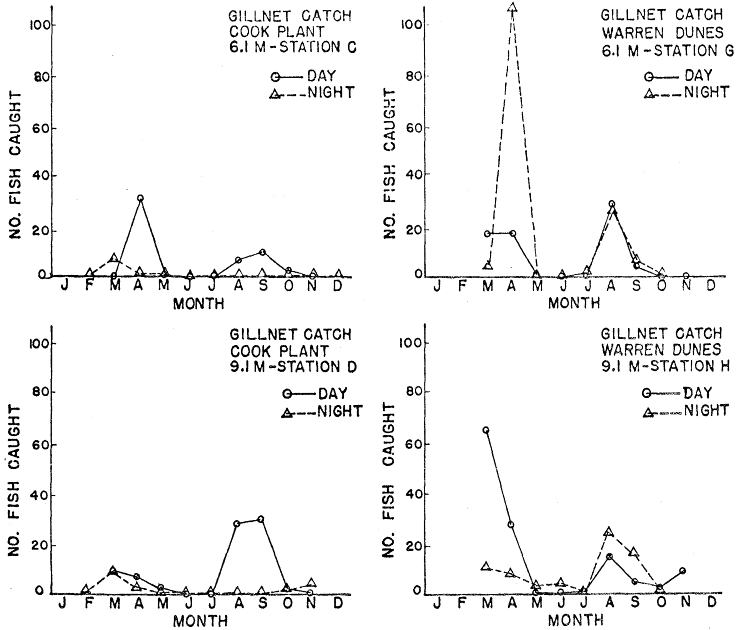


FIG. B21. Number of smelt caught in gillnets set during day and night once per month February through December, 1973 in southeastern Lake Michigan.

TABLE B19. Summary of nonparametric analyses for smelt, mostly adults, caught in standard series gillnets in the Cook Plant study areas April 1973. NS = not significant.

Factor (and levels)	df	Kruskal-Wallis statistic value	P
Area (Cook Plant, Warren Dunes)	1	2.0833	.1489 NS
Depth (6.1 m, 9.1 m)	1	.7500	.3865 NS

back and forth between spawning areas and 6.1-m or deeper contour.

As expected, in May, June and July adults were virtually absent from all stations, since smelt retreat to cooler, deeper waters soon after spawning. In August and September, catches again increased because of upwellings, during which smelt follow cold-water masses inshore. In October and November, catches were again low as smelt resided mainly in deeper water (Wells 1968).

Seines. Because of the highly variable habitat in the immediate beach zone area and the almost total absence of smelt during the year with the exception of large catches in April (Fig. B22), the seining catch was analyzed using the nonparametric Kruskal-Wallis test (Table B20). No significant ($P = 0.87$) differences in catches of smelt were found among the three seining stations. When the two Cook Plant stations were pooled and compared to Warren Dunes, differences were again non-significant ($P = 0.60$).

Seasonal Distribution by Age-Size Class

Subtle but chronic effects of thermal discharges may be detectable through changes in growth rates or in the temporal and spatial distribution of age classes. Relative sizes of smelt among various age classes were taken from the literature to approximate the age of fish in our sample (Table B21). Scale samples taken from representative fish have not yet been analyzed. Thus, except for the obvious YOY, yearling and adult (2 yr and greater) general classifications, a more precise age-class break-down is, at best, tenuous. Furthermore, overlapping lengths for different age classes and size segregation complicates interpretations. Data from the literature (Table B19) were compared with our composite monthly length-frequency histograms (Figs. B23, B24, B25) which we derived from

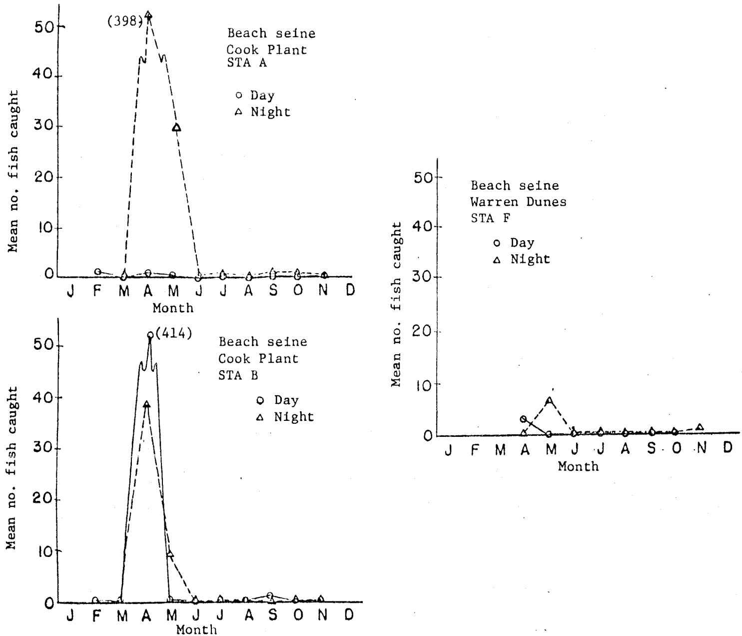


FIG. B22. Mean number of smelt caught in seines fished during day and night once per month February through November 1973 in southeastern Lake Michigan.

TABLE B20. Summary of nonparametric analysis of smelt caught in standard series beach seines in Cook Plant study areas April and May 1973. NS = not significant; S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic Value	P
Station (A, B, F)	2	.2738	.87 NS
Area Cook (A, B); Dunes (F)	1	.2709	.60 NS
Month (April, May)	1	3.7408	.05 S

TABLE B21. Average length of several year classes of rainbow smelt as found in the literature.

Age (year class)	Location: Miramichi[1] River, Canada	Lake Huron	Lake Superior	Gull Lake,[1] Michigan
0	----	----	----	60[2]
I	----	----	66[3]	150
II	137[4]	117[5]	151	163
III	156	155	190	188
IV	176	183	211	198
V	194	----	228	186

[1] These lengths are the averaged lengths of males and females.

[2] Burbidge 1969.

[3] Bailey 1964.

[4] McKenzie 1964.

[5] Baldwin 1950.

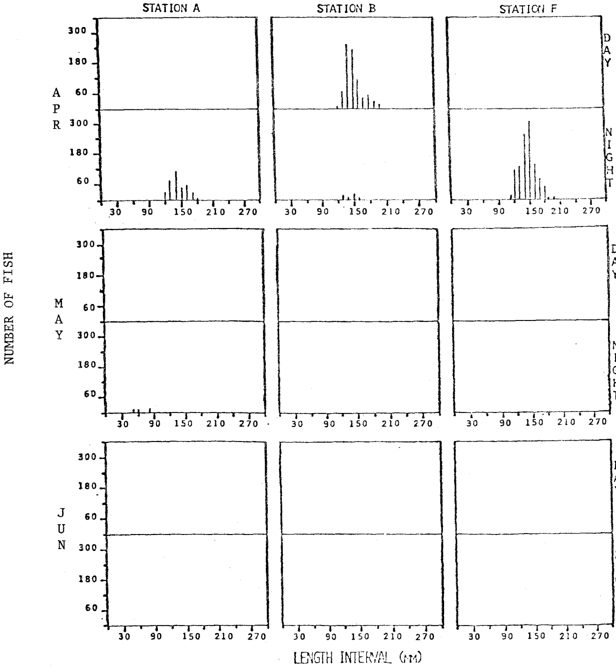


FIG. B23. Length-frequency histograms for smelt caught in standard series seining during 1973 in the Cook Plant study area of southeastern Lake Michigan.

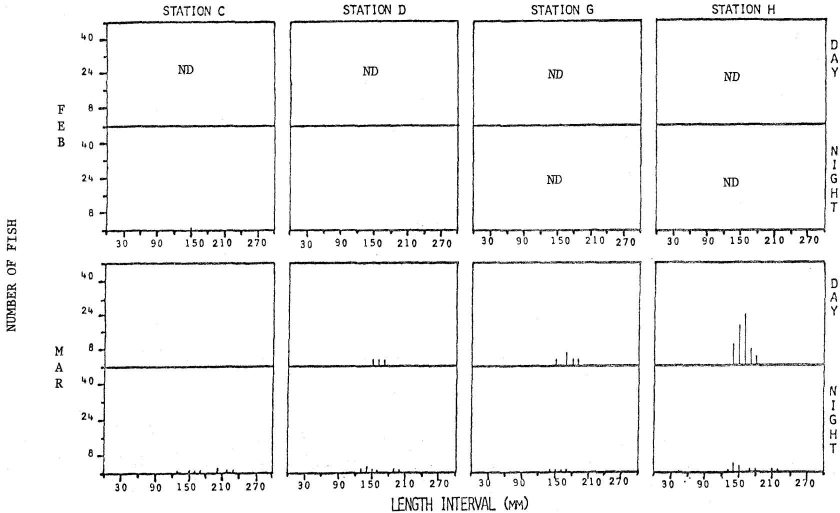


FIG. B24. Length-frequency histograms for smelt caught in standard series gillnetting during 1973 in the Cook Plant study area of southeastern Lake Michigan (ND = no data).

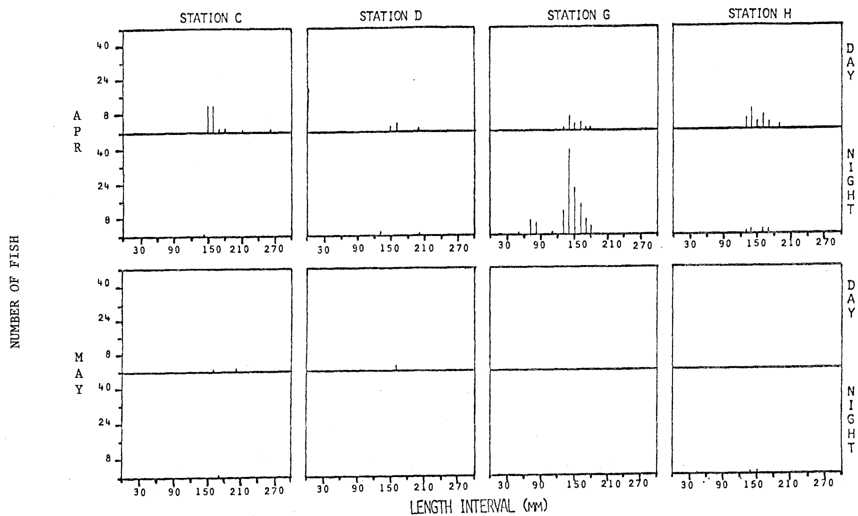


FIG. B24 continued.

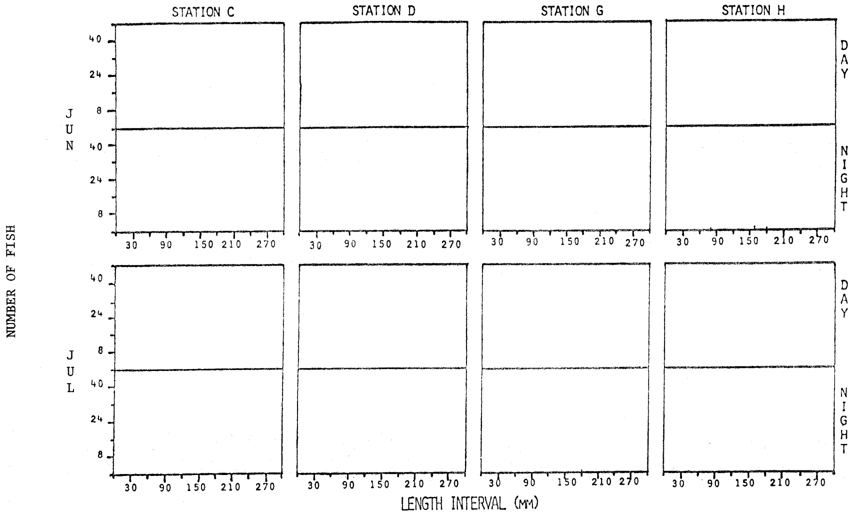


FIG. B24 continued.

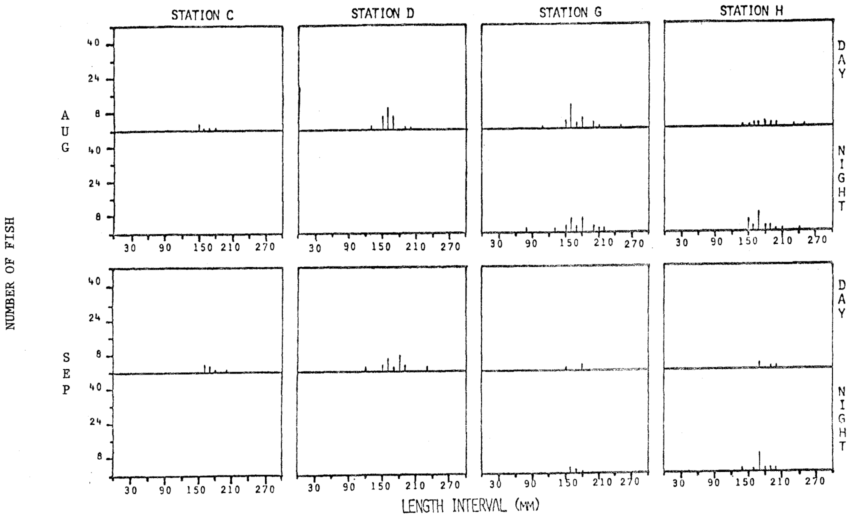


FIG. B24 continued.

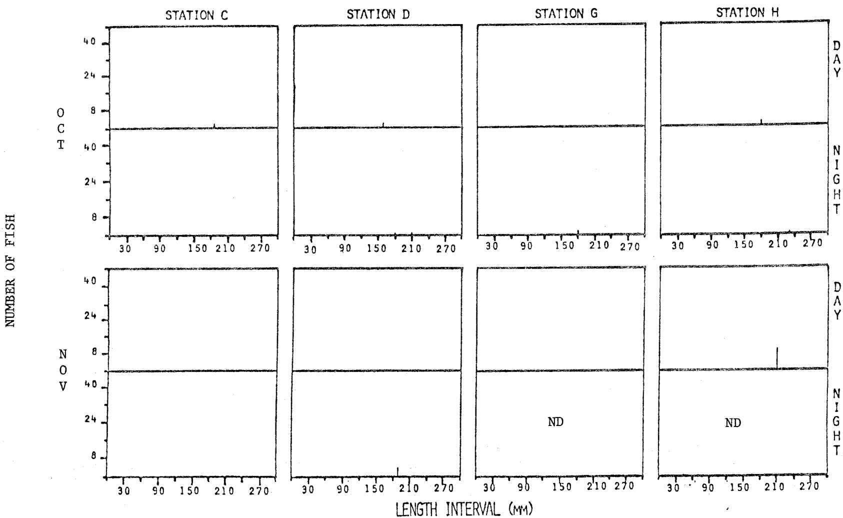


FIG. B24 continued.

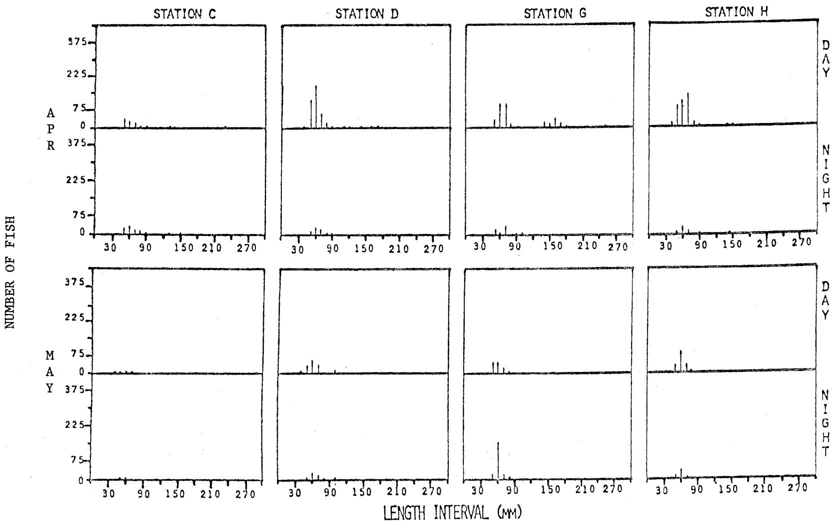


FIG.B25. Length-frequency histograms for smelt caught in standard series trawling during 1973 in the Cook Plant study area of southeastern Lake Michigan (ND = no data).

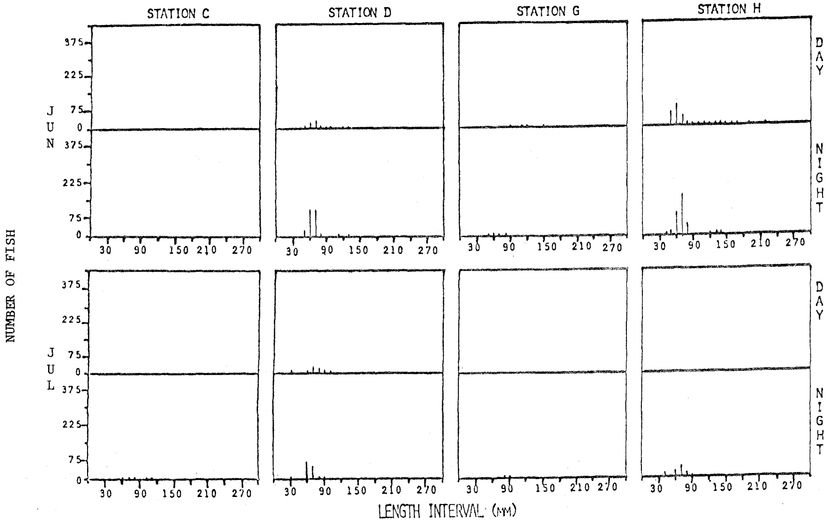


FIG. B25 continued.

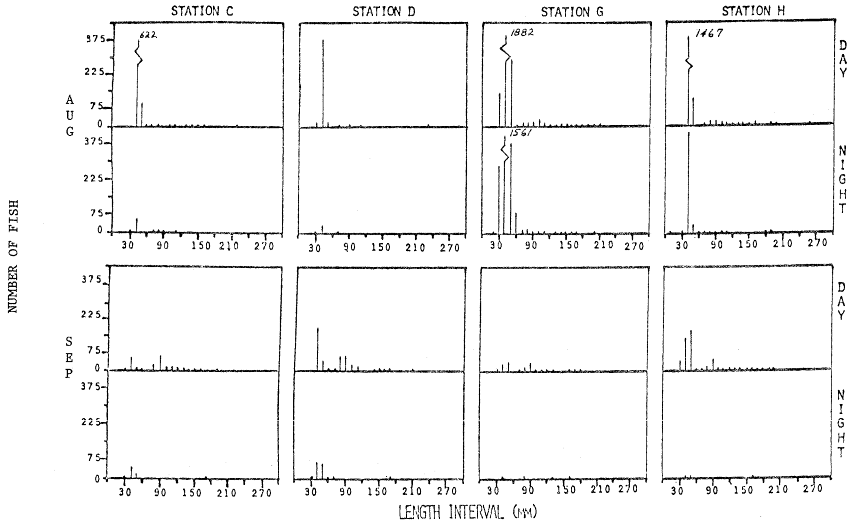


FIG. B25 continued.

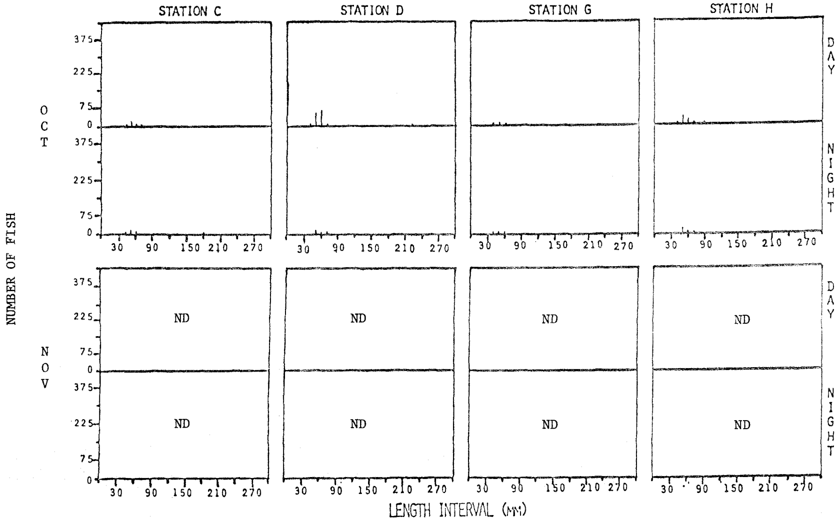


FIG. B25 continued.

standard series catches. Our data appear to approximate most closely average lengths reported by McKenzie (1964) from the Miramichi River.

Young-of-the-Year. Spawning in the Cook Plant vicinity takes place primarily in the beach zone and at the mouths of two small streams, one near Weco Beach and one at Warren Dunes. Spawning has been reported to occur in deeper water (9-22 m) in Lake Erie (MacCallum and Regier 1970). Peak spawning occurred during the last 2 weeks of April in 1973 and in 1974 extended into May. Larvae remained in the inshore area for a short time, then appeared to migrate to deeper (6.1 and 9.1 m) waters. A vertical migration of YOY smelt off the bottom at night is hypothesized (see Section C). A similar migration was documented for adults in Lake Erie by Ferguson (1965). Our sled tows to collect fish larvae, performed in May, June and July 1974, documented that in the inshore zone near the 6.1-m and in particular the 9.1-m contour at least some, if not all, the YOY remain on the bottom. Few were taken in shallower waters, and since sled tows in our studies were not performed deeper than 9.1 m, smelt YOY may extend to deeper contours. In eastern Lake Erie, Ferguson (1965) reported YOY smelt frequented shallow, epilimnial waters and at times were highly concentrated near shore. Our first major catches of YOY in standard series trawls occurred in August (Fig. B25). Modal length of YOY then was 40 mm. They were captured at all stations during this period, indicating their wide distribution during this time of the year. YOY did not occupy the beach zone, none were caught in seines, and since an upwelling occurred during this period they were apparently little affected by it.

In September YOY were again caught in trawls at all stations; more were caught during the day. Modal length at this time was approximately 45 mm.

In October, YOY smelt had grown to a modal length of 54 mm and were still present in the inshore zones, as evidenced by their appearance in all trawl catches at every 6.1-m and 9.1-m station.

Yearlings. In April and May, yearlings with a length of approximately 65 mm were present in modest numbers at all stations, with diurnal catches generally largest (Fig. B25). Yearlings were seined at night in May, suggesting this size class extended its activities into the beach zone. This was the only time yearlings were seined, therefore use of the beach zone may be limited to this brief period of the year. In June and July, yearlings apparently moved outside the 6.1-m contour area, as few were captured at this depth whereas many were taken both during the day and night at 9.1 m. August and September catches of yearlings were sparse, although a few fish were taken at nearly every station fished. Modal length of yearlings had increased from 65 mm in April to about 90 mm in September. It appears that yearlings began to migrate from the study area in August and September, completing their departure by October since none were trawled then. Wells (1968) recorded appreciable numbers of young smelt in trawl catches taken from Lake Michigan on 14 October and

again on 4 November 1964. Most were found in 18-22 m of water, confirming the fall movement of yearling smelt to deeper water.

Adults. Two adult smelt were taken in a gillnet in February (Fig. B24). The bulk of the adult population is concentrated in deeper water at this time (Wells 1968), but this catch indicates that a few smelt range into inshore waters during winter. In March, smelt were caught in modest numbers at all 6.1-m and 9.1-m stations, though none were seined at the two Cook Plant stations. Apparently smelt were moving inshore to spawn; however, as of March, none had entered the beach zone.

In April our seining corresponded with the spawning peak of smelt. At this time gonad data (Table B22) indicate spawning was indeed in progress, as many ripe-and-running males and females were recorded in seine catches particularly, but also in gillnet catches. The general pattern of diel movement was an onshore movement at night, followed by the actual spawning act, and an offshore movement during the day. This diel pattern is evidenced by higher nighttime than daytime catches in seines, and by the fact that April gillnet catches were highest during the day although smelt were also caught in night sets. This pattern, however, was not entirely consistent as large daytime seine catches were recorded at station B. Our only explanation is that apparently the sheltered nature of station B and the shallow shoal area attracted smelt to such a degree that they remained in the area during the day rather than moving offshore as they did in other areas. Trawl catches of adult smelt were negligible in April and the remainder of the year, suggesting that adults often avoid the trawl.

During May, June and July few adult smelt were taken within the 9.1-m contour. After spawning they moved to deeper, cooler waters and remained there during warmer months. Incidental catches of smelt in gillnets and trawls occurred during upwellings when fish apparently followed cold-water masses inshore. Such an upwelling was recorded in August and September, at which time small catches of smelt were taken in gillnets. Wells (1968) showed that after spawning in April smelt moved offshore to deeper water; they were present out to 18 m in early May to 27 m by late May through August, and were dispersed throughout deeper parts of the lake in October and November. Ferguson (1965) also noted that smelt avoided warm inshore waters. Ferguson (1965) found that Lake Erie adult smelt begin moving toward the surface in late afternoon, remain there at night (though feeding did not occur), then return to the bottom in late morning, at which time maximum feeding occurred.

After September, adult smelt in the Cook Plant vicinity were scarce; however, a few individuals were caught at almost all stations in October and November, indicating that at least part of the population ranged into inshore waters during the fall.

Temperature-Catch Relationships

Preferred temperature for adult smelt was reported by Ferguson (1965)

TABLE B22. Monthly gonad conditions of rainbow smelt as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
					Females					
Poorly dev.							3	21	13	3
Mod. dev.		3					1	6	6	3
Well dev.	18	79	201	4						
Ripe-running			57	1	4					
Spent			30	6			49	12	2	
					Males					
Poorly dev.		2			1	1	4	35	8	1
Mod. dev.	1	11	20		1		5	23	7	1
Well dev.	6	26	188	1	2					
Ripe-running			17							
Spent			26	11	13	1	31	13		
					Unable to distinguish					
			12	4	33	6	109	45	1	

to be 6.1 C; Wells' (1968) data show 6-14 C as preferred temperatures for smelt. The majority of trawl-caught smelt in our study, mostly YOY and yearlings, were taken at temperatures between 12 and 14 C (Fig. B26).

To adequately delineate temperature-catch relationships for adults, gillnet data are used inasmuch as few adults were caught in trawls. Maximum numbers of smelt were caught in gillnets when temperatures were between 6 and 8 C. The suggested temperature preference of 6-8 C agrees well with the 6.1 C and 7.2 C preferred temperatures reported by Ferguson (1965) and Hart and Ferguson (1966) respectively.

Although seines caught adults exclusively, these catches were not considered in the determination of temperature preference since the majority of these fish were spawning adults with accompanying behavior modifications. Peak catches occurred at 8-10 C. Scott and Crossman (1973) stated that smelt do not spawn until water reaches 8.9 C.

Summarizing, three temperature regimes were apparent: 1) yearling and YOY smelt were most frequently caught at 12-14 C, 2) a temperature of maximum catch

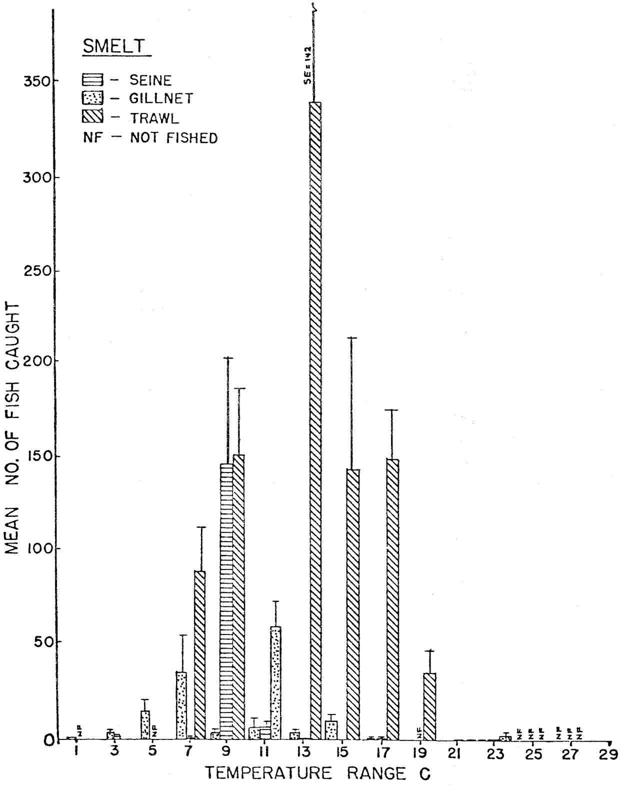


FIG. B26. Mean catch and standard error of smelt at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

between 6-8 C is indicated for adults, and 3) spawning appeared to peak when water temperatures reached 8-10 C.

Other Considerations

Smelt were commonly found in stomachs of salmonids during certain times of the year, indicating smelt to be an important forage fish along with sculpins and trout-perch, in the event alewife populations should ever become decimated. Because they are fed upon by salmonids, which feed throughout the water column; it may also be suggested that smelt spend more time off the bottom (documented by Ferguson 1965) than does the more demersal spottail for example, which is seldom eaten by salmonids. However, there may be other reasons why spottails are not preyed upon significantly.

We did not record any external or internal diseases or abnormalities in smelt.

Yellow Perch

Yellow perch and Eurasian perch, similar species, combined have an almost circumpolar distribution in fresh waters of the northern hemisphere (Scott and Crossman 1973). Today yellow perch occur throughout most of North America, having been introduced in many areas. They inhabit waters of moderate temperatures from large lakes to ponds or quiet rivers and reach greatest abundance in rather fertile waters with large plankton crops and rich bottom fauna. Large bays of the Great Lakes are typical of such waters, and Green Bay in Lake Michigan has been an excellent habitat for yellow perch.

Yellow perch have been an important sport and commercial fish in Lake Michigan, with annual commercial harvests averaging 1.1×10^6 kg (2.4×10^6 lb). Since catch records were begun in 1889 (Wells and McLain 1973), yellow perch yields have fluctuated widely, and in the early 1960's a production peak crashed coincident with and paralleling spread of alewives in Lake Michigan. Following the drastic decline of the alewife population in 1967-68, yellow perch responded with a strong 1969 year class.

Because of its commercial and recreational importance, there is considerable literature on various aspects of the life history of yellow perch (Scott and Crossman 1973), which will not be dealt with here. In Lake Michigan several studies have been performed in and around Green Bay on yellow perch distribution, growth and food habits (Hile and Jobes 1942; Mraz 1952; Joeris 1957; Toth 1959; Dodge 1968). Although yellow perch are common in the rest of the lake we could find only two investigations pertaining to yellow perch in southern Lake Michigan (Wells 1968; Brazo 1973). More documentation is needed concerning the niche of this important fish in Lake Michigan, to better understand its economic and ecological value.

Statistical Analysis of Yellow Perch Catch

Trawls. Analysis of variance of 1973 trawl catches of yellow perch (Table B23) indicates no significant difference ($P > .01$) between populations off Cook Plant and those off Warren Dunes. However, two of the first-order interactions--MONTH x DEPTH and MONTH x TIME of day (Table B23) --were highly significant ($P < .01$)

Explanation of the interactions will be attempted through examinations of seasonal migrations of yellow perch as demonstrated by plotting the monthly geometric mean values of numbers of perch caught by depths, 6.1 m and 9.1 m, and pooled over stations and time (day and night) (Fig. B27). We will attempt to discuss interactions by pointing out discrepancies and irregularities in observed trends. Yellow perch were scarce at all trawl stations in April and May but appeared in abundance at 6.1-m stations in June. Failure to catch many yellow perch at 9.1 m in June suggests that most of the perch populations had migrated to shallow waters, within the 9.1-m contour, between May and June. Yellow perch remained concentrated inshore during June and July, and analysis of gonad conditions (Table B24) clearly revealed that they spawned in early June. These results are in close agreement with observations that yellow perch in Lake Michigan near Ludington migrate *en masse* to the littoral zone in late May (water temperature = 7 C), and spawn in June at water temperatures near 11 C (Brazo 1973). Whether or not yellow perch spawn in the vicinity of the Cook Plant is as yet unconfirmed.

Peak offshore (9.1 m) trawl catches in August and September suggest a general offshore migration, which was completed before the October sample period. This shift from higher inshore (6.1 m) catches in August to higher offshore (9.1 m) catches in September probably contributes much to the significance of the MONTH x DEPTH interaction. In the absence of extensive orthogonal contrasts and/or multiple comparison tests, one can roughly index the contribution of each cell to the interaction by the following formula:

$$X_{ij} = M_{ij} - M_{.j} + M_{..}$$

where:
X_{ij} = interaction effect (see Cohen 1969)
M_{ij} = cell mean of the ith row and jth column
M_{i} = ith row mean (Eq. 1)
$M_{.j}$ = jth column mean
$M_{..}$ = grand mean of all cells.

This simple procedure indicates that the greatest interaction effect occurred in September, followed by another high interaction effect in June. Similar conclusions may be drawn through examination of Figure B27.

The general picture of seasonal migrations indicated by the MONTH x DEPTH interaction agrees with earlier trawl studies in southeastern Lake Michigan. It has been found that yellow perch are offshore at about 20 m

TABLE B23. Summary of analysis of variance for yellow perch caught in trawls in the Cook Plant study areas from June through October 1973.

Source of variation	df	Adjusted mean square[1]	F-Statistic	P
AREA	1	.00428	0.04	NS[2]
MONTH	4	.84163	8.70	<.01
DEPTH	1	1.52628	15.77	<.01
TIME of day	1	.06315	.65	NS
AxM	4	.08685	.90	NS
AxD	1	.14712	1.52	NS
AxT	1	.39739	4.10	<.05[3]
MxD	4	1.12924	11.67	<.01
MxT	4	2.89516	29.91	<.01
DxT	1	.02140	.22	NS
AxMxD	4	.16485	1.70	NS
AxMxT	4	.22534	2.33	NS
AxDxT	1	.03864	.40	NS
MxDxT	4	.03729	.39	NS
AxMxDxT	4	.05215	.54	NS
Within cell error	39[4]	.096793		

[1] Mean squares were multiplied by harmonic cell size/maximum cell size (n_h/N = 0.976) to correct for 2 missing observations where the cell mean was substituted.

[2] Not significant (P>.05).

[3] Not significant (.01 <P <.05).

[4] One degree of freedom was subtracted to correct for one missing observation where the cell mean was substituted.

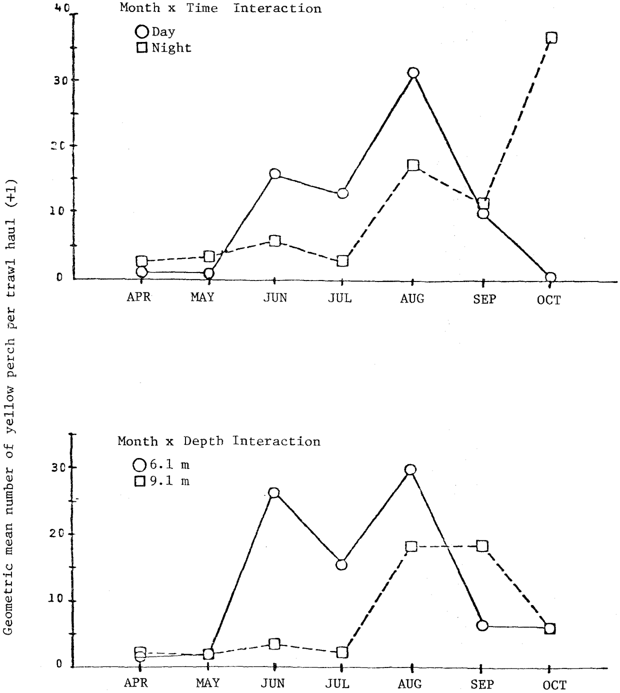


FIG. B27. Geometric mean number of yellow perch caught in duplicate trawl hauls during the day and night (stations and areas pooled) and at 6.1-m and 9.1-m stations (areas and time of day pooled) in southeastern Lake Michigan. April and May data were excluded from the ANOVA.

TABLE B24. Monthly gonad conditions of yellow perch as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.			2	4	4	1	63	24	97	8	4
Mod. dev.		1	1	1	4	1	6	7	2	16	
Well dev.	3	17	11	19	20	2			1		
Ripe-running					4						
Spent					494	253	197	50	12	1	
					Males						
Poorly dev.		1			3		75	33	35		2
Mod. dev.	5	4	7	8	9	2	20	25	101	24	1
Well dev.	1	17	6	14	34	15	1	5	4		4
Ripe-running											
Spent				1	157	178	161	15			
					Unable to distinguish						
					23	2	3	1	1		

depth from February through May, move inshore in late May, remain at depths less than 13 m through the summer and migrate offshore again by October or November (Wells 1968).

The MONTH x TIME of day interaction plot (Fig. B27) indicated that from June through August yellow perch were more vulnerable to trawls during the day than at night, but in October there was a complete reversal. Indeed, the largest interaction effect (from Eq. 1) for any cell occurred in October. Whether this reversal reflects a change in diel activity or a change in spatial abundance in not known. However, the observed MONTH x TIME of day interaction could be explained through the existence of a diel pattern of nocturnal shoreward movement combined with seasonal movements of the population. During summer months June, July, August, the bulk of the population is located inside the 6.1-m contour. Day trawl catches would be heightened as a result of predominate diurnal activity characteristic of yellow perch, but evening onshore movements of these fish and hence the population itself would occur inside of the trawl zones, resulting in low nocturnal catches. As the yellow perch population moves offshore in the fall (September, October, November), diurnal and overall catches would be expected to decrease as is reflected in our data. However, evening onshore

migrations might now bring the population inshore and into the trawl zones, which would result in heightened nocturnal catches (Fig. B27). In other words, diel catch variation of yellow perch may be explained in terms of crepuscular onshore-offshore movements. The extent to which these movements and the diel location of the population itself are reflected in trawl catches will in turn vary with the seasonal pattern of spatial migration of yellow perch. Crepuscular movement--inshore at dusk, offshore at dawn--has been noted for yellow perch in Lake Mendota, Wis. (Herman et al. 1969).

To summarize the analysis of trawl data, differences between the two study areas seem to be minimal; significant seasonal distribution changes indicate large scale onshore-offshore migrations, and seasonal changes in diel catches suggest a year-around daily movement inshore at night and offshore by day.

Gillnets. Gillnet catches were analyzed using the nonparametric Kruskal-Wallis test to test for the effects of depth, area and month (Table B25). No differences were found between abundance of yellow perch at the Cook Plant and Warren Dunes. Similarly, there were no significant ($P < .05$) differences between 6.1-m and 9.1-m gillnet sets. As expected, effects due to month were highly significant ($P = .0005$).

It is possible to make qualitative observations about yellow perch gillnet catch. Gillnet catches (Fig. B28) were characterized by higher day catches than night with three minor exceptions which occurred in August, October and November. Highest catches occurred during the summer, which not only reflect abundance but also activity of yellow perch. It appears that perch are more active during the day, but inferences drawn from gillnet data may be seriously biased since evidence indicates that yellow perch follow crepuscular activity patterns (Herman et al. 1969). Hence exact times of peak activity will change seasonally. Due to the logistics

TABLE B25. Summary of nonparametric analyses of yellow perch gillnet data 1973. NS = not significant, S = significant at the 0.05 level.

Factor (and levels)	df	Kruskal-Wallis statistic		Mann-Whitney U statistic	
		Value	P	Value	P
Month (May-Sep)	4	20.12800	.0005 S	-----	-----
Depth (6.1 m, 9.1 m)	1	.04561	.8309 NS	377.0	.8305 NS
Area (Cook Plant, Warren Dunes)	1	.07485	.7844 NS	344.0	.7840 NS

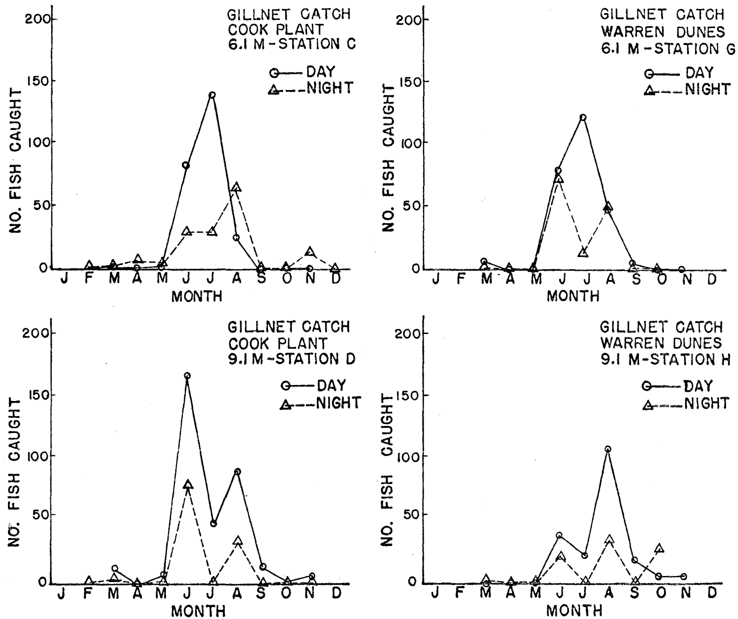


Fig. B28. Number of yellow perch caught in gillnets set during day and night once per month February through December 1973 in southeastern Lake Michigan.

of setting and pulling nets, night gillnet sets probably overlap the early morning activity period and day gillnets may be removed from the water before the evening activity period commences. Observations by our SCUBA divers indicate that yellow perch were generally inactive at night, either resting on the bottom or suspended in the bottom 2 m of the water column. Since non-moving fish have a low probability of being gilled, this appears to confirm that most night catches were biased upward by net times overlapping crepuscular activity periods.

Seines. Yellow perch were abundant in the beach zone only during June, with mostly yearlings captured; seining February through May yielded no yellow perch. In July and August a few small individuals were captured (Fig. B29), and in October about 50 YOY and yearlings were taken at Warren Dunes at night.

Nonparametric tests for differences between the beach stations (A, B and F), and between the Cook Plant and Warren Dunes study areas were carried out using the Kruskal-Wallis test (Table B26). June was the only month for which there were sufficient data to make such tests, and neither test was significant ($P > .05$). Although a test was not made, there did not appear to be noticeable differences between day and night catches in the beach zone, except in October at Warren Dunes as previously noted.

Seasonal Distribution by Age-Size Class

In addition to changes in abundance parameters, subtle effects of the Cook Plant thermal discharges may be detected through analysis of growth rates and temporal and spatial distributional patterns of various size classes. Scale samples for analysis of growth rates of yellow perch from study areas have been taken but not yet analyzed. To facilitate the ensuing discussion, average sizes of yellow perch at the end of each growth season were compiled (Table B27).

As a preliminary approximation of seasonal growth, monthly composite length-frequency histogram summaries were compiled using data from both standard series and supplementary samples (not shown). Length modes indicated in our standard series length-frequency histograms for YOY and yearlings (Figs. B30, 31, 32) are generally distinct, whereas discrete length modes for larger classes (older fish) are frequently difficult to distinguish. Therefore the extent to which length modes are confounded by segregation according to size rather than age is unknown; a definitive answer must await scale analysis, but our data will suffice for the present discussion. It should also be pointed out that length modes greater than 100 mm may be biased upward slightly by inclusion of gillnet data.

Young-of-the-Year. YOY yellow perch first appeared in July in beach seine samples at sizes of about 25 mm (Fig. B30, Table B28). This is consistent with our deduced June spawning, an incubation period of 8-10 days (Herman et al. 1969, Lake Mendota, Wis.) and an approximate first

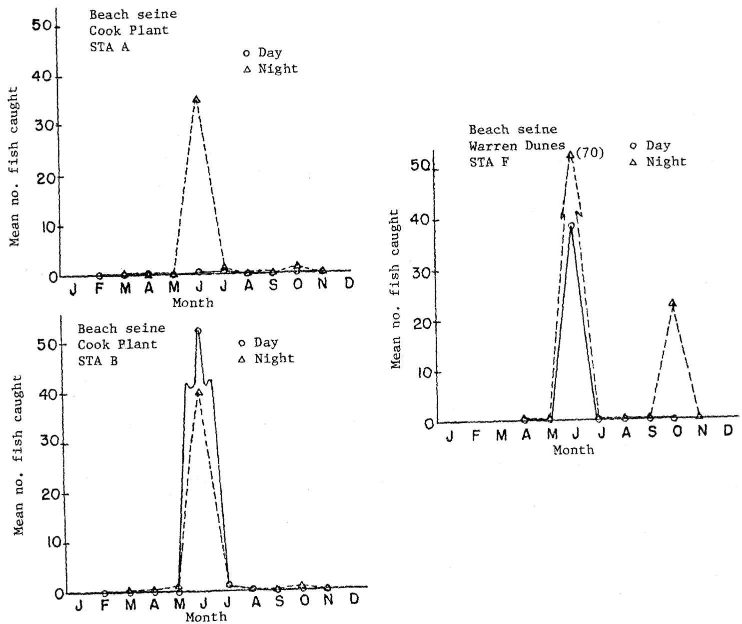


FIG. B29. Mean number of yellow perch caught in seines fished during day and night once per month February through November 1973 in southeastern Lake Michigan.

TABLE B27. Calculated mean size (total length in mm) of yellow perch at the end of their respective year of life for various locations. M = male, F = female, C = combined.

Location	Source	Sex	Year of life 1	2	3	4	5	6	7	8	9
Klamath River, California	Coots 1956[1]	C	90.2	150.4	194.8	230.1	269.5				
Lake Erie[2]	Jobes 1952	C	94.0	170.2	215.9	241.3	264.2	279.4			
Lake Michigan[2]	Van Oosten 1948	C	71.1	114.3	152.4	180.3	215.9	246.4			
Saginaw Bay, Lake Huron	el-Zarka 1959[3]	M	66.0	106.6	142.2	170.2	193.0	215.9	236.2		
		F	68.6	109.2	149.9	190.5	223.5	259.1	281.9	297.2	309.9
Lake Erie	Parkhurst 1971[4]	C	73	134	172	194	201	212			
Big Bay de Noc, Lake Michigan	Toth 1959	M[5]	71	105	141	185	215				
		F[6]	71	109	147	188	222	251	289	308	
Lower Red Lake, Minnesota	Pycha and Smith 1955		56[7]								
			68[8]								

[1] Table 1, p. 221
[2] Taken from Coots 1956, Table 2, p. 222
[3] Table 31, p. 391
[4] Table 5, p. 43, weighted mean
[5] Table 8, p. 41
[6] Table 7, p. 40
[7] YOY, length on August 19
[8] YOY, length on October 9

TABLE B26. Summary of nonparametric analysis of yellow perch beach seine data, June 1973 only. NS = not significant.

Factor (and levels)	df	Kruskal-Wallis statistic Value	P
Station (A,B,F)	2	3.0385	.21 NS
Area Cook (A,B), Dunes (F)	1	.2596	.61 NS

month's growth of 36 mm (Pycha and Smith 1955, Red Lakes, Minn.).

YOY perch were taken at all trawl stations in August, September and October (Fig. B32) at respective modal sizes of 65, 80 and 90 mm. Yellow perch YOY from Red Lakes were 56 mm in mid-August and 68 mm in early October. The presence of YOY perch at trawl stations indicates a general offshore dispersal; however, impingement samples taken in December (Table D1, Sec. D) suggest that at least some smaller individuals remain inshore, perhaps among the riprap surrounding the Cook Plant's intake structures. No YOY yellow perch were taken in gillnets; only perch approximately 100 mm or longer were gillnetted.

Offshore dispersal of YOY yellow perch in late summer has also been noted for populations in Lake Erie (Wells 1968) and Lake Mendota (Herman et al. 1969), but for some reason, no YOY and only a few yearling yellow perch were caught during extensive trawling operations in southeastern Lake Michigan, in water as shallow as 5 m (Wells 1968). L. Wells (personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service) suggests that the reason they did not catch young perch is that hatches in those days were poor.

Yearlings. Yearling yellow perch, 1972 year class, were consistently taken from January through March in impingement samples (Table D1, Sec. D). Incidental trawl catches of 70-mm yearlings were taken at night in May (Fig. B32). This age class first appeared in abundance in the beach zone during June (Fig. B30) but apparently moved offshore again by July. However, 1974 seining in July captured large numbers of yearlings, and August seining also produced some yearlings, indicating yearlings may utilize the beach zone for a longer period of time than indicated by 1973 data. By August and September 1973, the 1972 year class was consistently caught in trawls (Fig. B32). Yearlings were first encountered in gillnets at a size of about 110 mm in July at station C (6.1 m), and 140 mm yearlings were gilled in August at most stations (Fig. B31).

The general pattern for yearling yellow perch appears to be wide dispersal during the winter between first and second growth seasons,

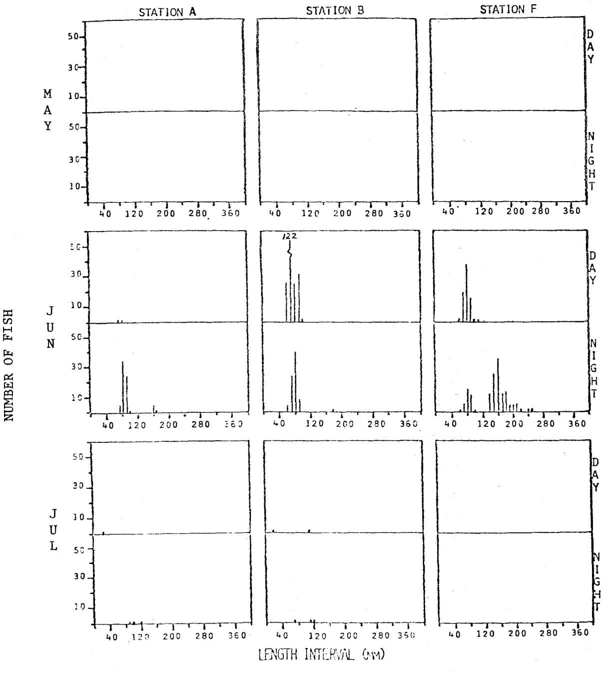


FIG. B30. Length-frequency histograms for yellow perch caught in standard series seining during 1973 in the Cook Plant study area of southeastern Lake Michigan.

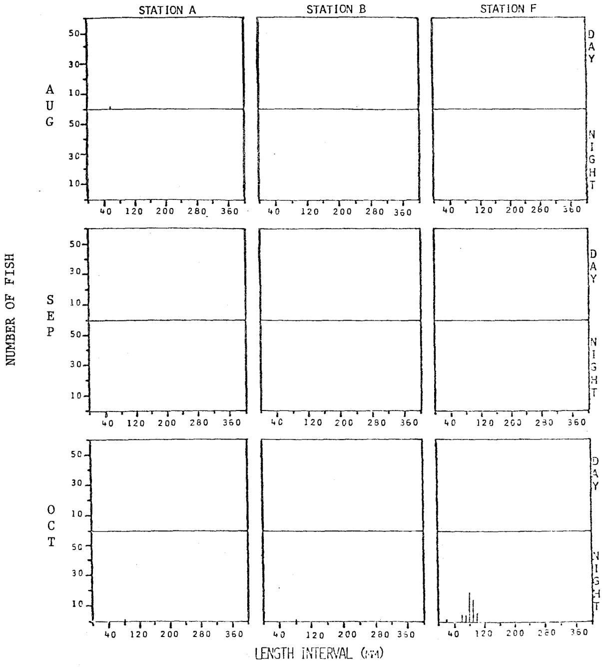


FIG. B30 continued.

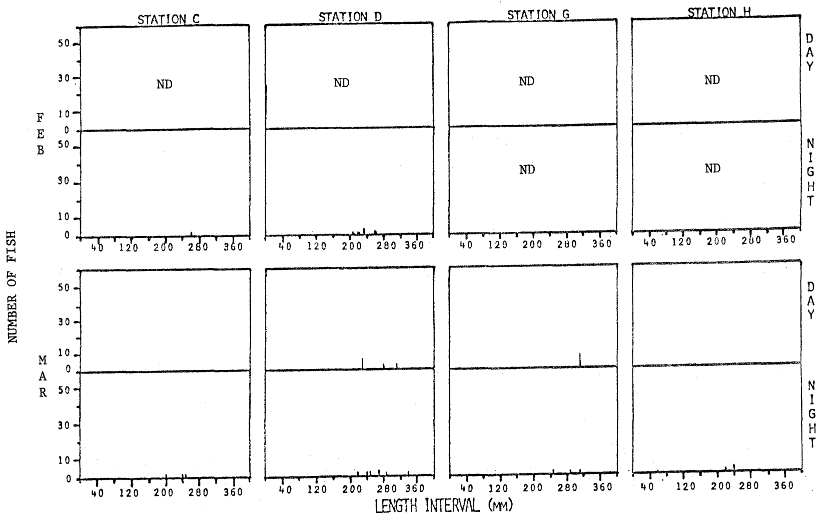


FIG. B31. Length-frequency histograms for yellow perch caught in standard series gillnetting during 1973 in the Cook Plant study area of southeastern Lake Michigan. ND = no data.

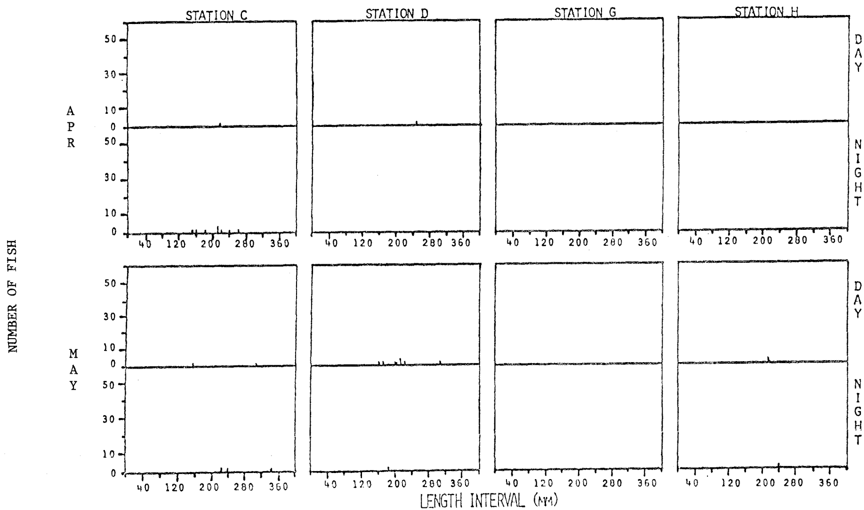


FIG. B31 continued.

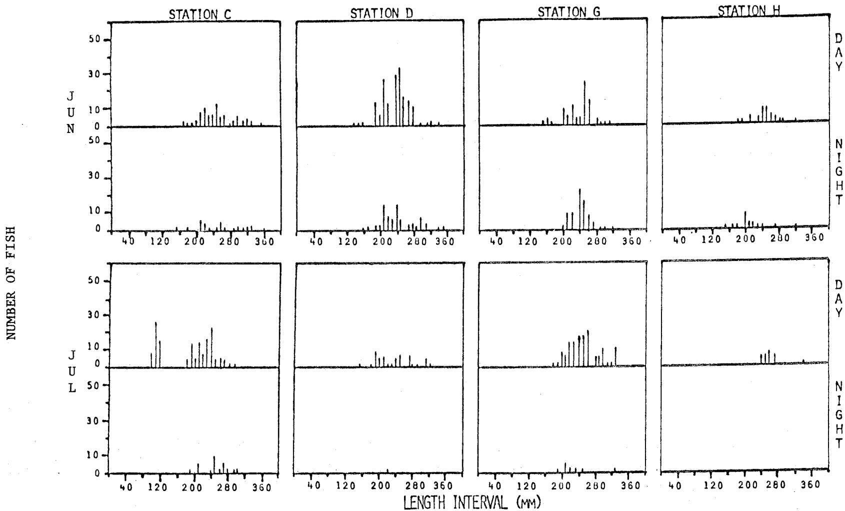


FIG. B31 continued.

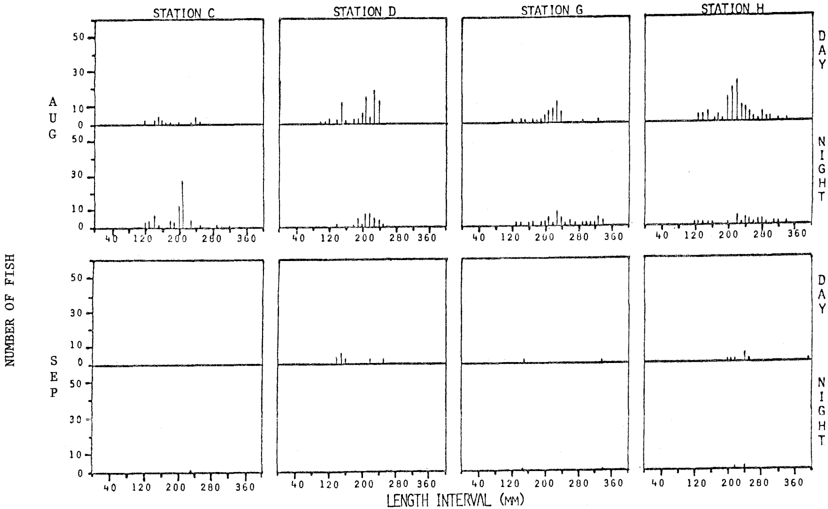


FIG. B31 continued.

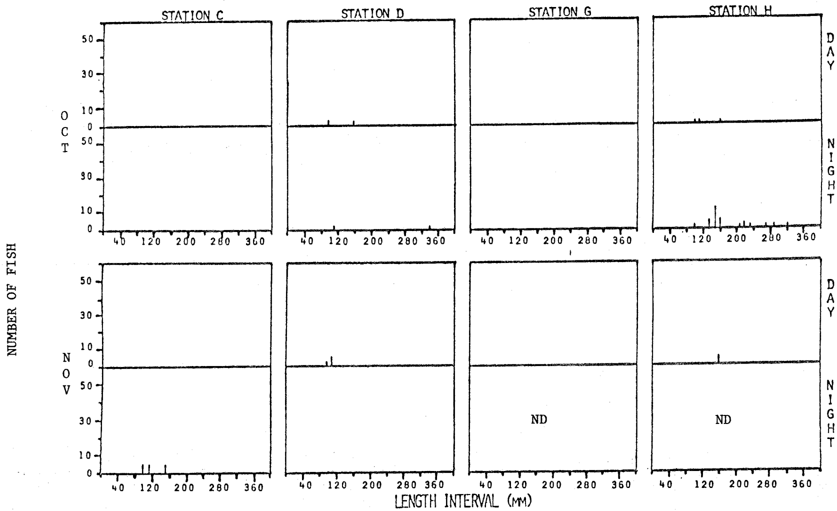


FIG. B31 continued.

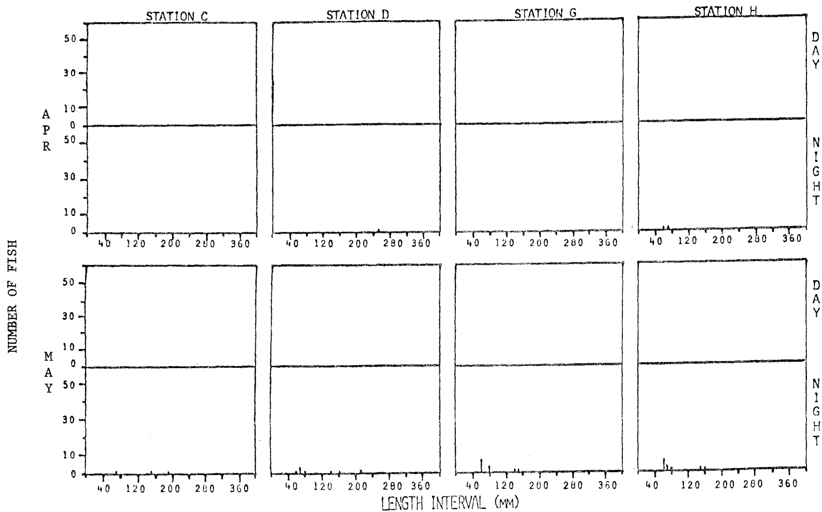


FIG. B32. Length-frequency histograms for yellow perch caught in standard series trawling during 1973 in the Cook Plant study area of southeastern Lake Michigan. ND = no data.

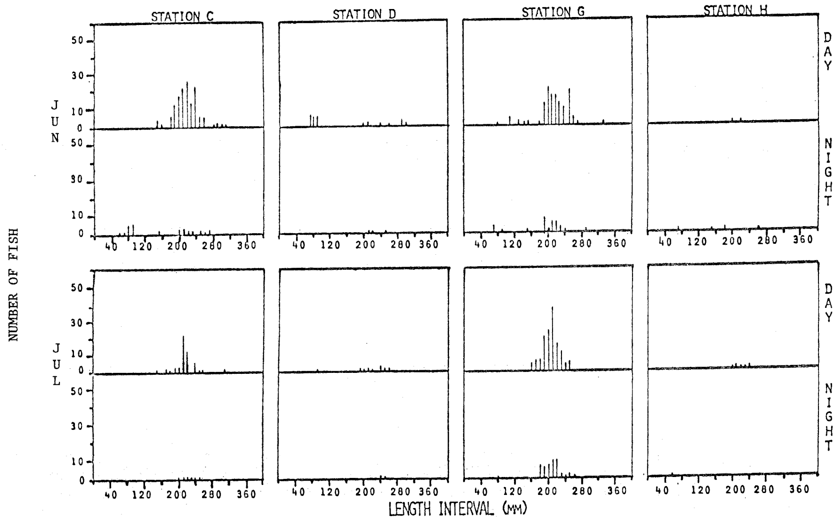


FIG. B32 continued.

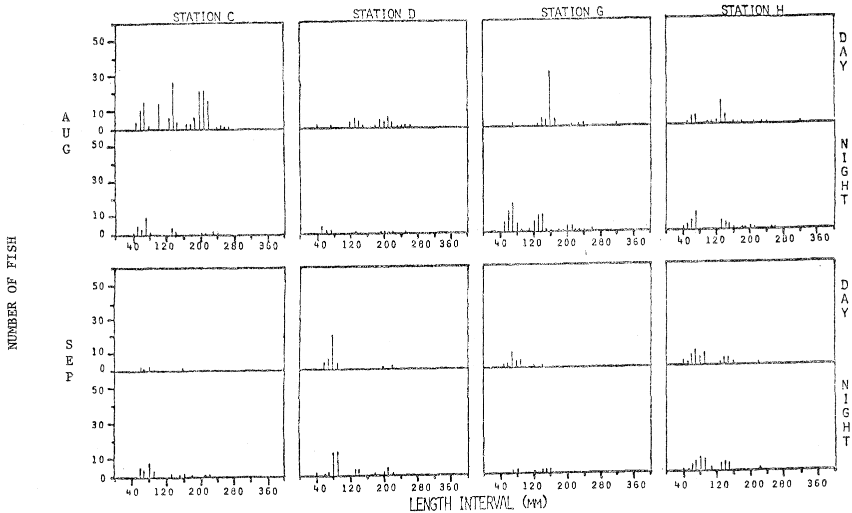


FIG. B32 continued.

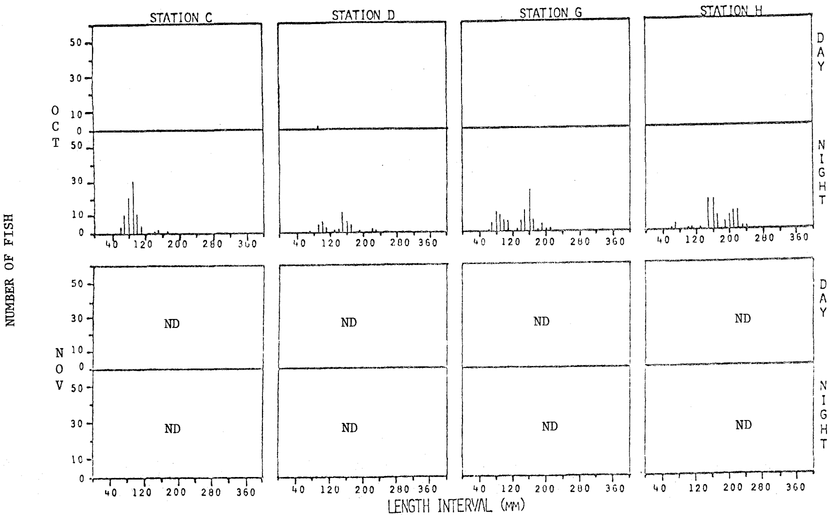


FIG. B31 continued.

TABLE B28. Growth of 1972 and 1973 year class yellow perch (modal total length-mm) during 1973 as deduced from monthly composite length-frequency histograms. April through October data were based mostly on standard series samples, January through March and December on impingement samples only, and November on gillnet samples only.

Year class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1972	65	65	70	65	70	80	110	140	140	150	160	---
1973	---	---	---	---	---	---	25	65	80	90	105	70

concentration in the beach zone in June, July and perhaps including August, and a gradual offshore dispersal in late summer.

Adults. Virtually all adult yellow perch are in deep water during winter, in contrast to the more widely dispersed yearlings. A few perch were taken in April and May, but June marked the most significant influx into our area, when large numbers were caught at 6.1-m stations. This large catch was associated with large gillnet catches at station A, 1-3 m deep, observed in 1973 (see Table B-41) and again, in particular, 1974. Concurrently, catches at 9.1-m stations were low, indicating the bulk of the adult perch population was in 1-6 m of water during this period. Few adults were taken in June seine hauls, which suggests adult perch may not utilize or enter to any great extent the shallow, less than 1-m, beachwater zone, even during periods of maximum inshore abundance.

Gonad data (Table B24) show that 651 of 729 (89.3%) yellow perch captured in June were spent. To determine that we did not simply fail to fish during the period in 1973 when ripe-running perch may have been in the study area, we conducted two series of gillnet sets in 1974, one supplementary set in early June, and a standard series set in late June. Very few fish were caught in the early sets and those captured in the late sets were all spent, as were the fish caught in 1973. SCUBA divers have been able to squeeze eggs and milt from a few perch captured while diving in the study area; however, spawning and egg masses have never been observed. We have tentatively concluded that yellow perch are spawning outside the 9.1-m contour or elsewhere in the lake, and only enter the inshore zone around the Cook Plant when most are spent.

From June through August, daytime locus of the perch population occurred at 6.1-m stations. For remaining months perch were migrating offshore, since in August and September perch were most often captured at 9.1-m stations at night, indicating the initiation of the fall-winter offshore migration which was complete by October. After August, daytime locus of the perch population appeared to remain in the vicinity of the 6.1 to 9.1-m contour until the seasonal offshore migration of perch was complete. Mraz (1952), in an early May tagging study of yellow perch

from Green Bay, showed that 79.5% (101 of 127 recaptured) of the fish were recaptured at the release site, 19.4% were taken within 38 km, 6.5% between 38-76 km and 1.9% between 76-92 km of the release site. Eighty-six of these fish were recaptured in late May, 21 in June and July, and one in September. Throughout the months we observed two types of migrational patterns: 1) the seasonal pattern of onshore-offshore movement just discussed, 2) a diel pattern of nocturnal shoreward movement followed by a diurnal retreat to deeper water. It is possible that this second migrational pattern may represent primarily crepuscular behavior; however, since an attempt was made to separate day and night fishing efforts we have little data taken during the crepuscular periods.

Temperature-Catch Relationships

According to Fry (1964), yellow perch cannot acclimate to temperatures above 32 C and have a final preferendum of 24 C. Final preferendum is defined as that temperature range in which fish will ultimately congregate in an infinite gradient (Fry 1947). Fry also found that laboratory determined thermal preferences, especially for warm-water species, were several degrees higher than those deduced from field observations. YOY yellow perch taken from Lake St. Clair and acclimated to 24 C in October and November selected temperature ranges from 23-24 C and 20-21 C respectively (McCauley and Read 1973). Adults from the Grand River acclimated to 24 C in June preferred temperatures of 18-20 C; those from Lake St. Clair acclimated to 24 C in October preferred 16-19 C. Scott and Crossman (1973) postulate a similar temperature preference and suggest that perch follow the 20 C isotherm in their seasonal movements.

Our data (Fig. B33) suggest two separate peaks of maximum catch for yellow perch. The first range for small and medium-size fish may be deduced from numbers caught in seines and trawls. Larger perch are infrequently caught in seines and trawls, thus these gear reflect temperature preference for smaller fish. Yellow perch were caught in trawls between 8 and 24 C with peak catches between 22 and 24 C. Seining data suggest that smaller fish, mostly yearlings, were caught in water temperatures from 20-24 C, which agrees fairly well with Ferguson's (1958) determination of 23.5 C. A second range for medium and larger-size perch can be deduced from gillnet data. Most gillnet-captured perch were taken between 16 and 22 C.

Other Considerations

Yellow perch were observed by SCUBA divers on several occasions during the day and once at night at the Cook Plant in the period between June and September 1973. Perch were seen only in areas adjacent to the intake and discharge structures, never in areas outside of the riprap (i.e., natural, undisrupted areas), which might indicate either positive attraction to the structures as a source of shelter, protection or as a better forage area or that these fish are more easily frightened from, and therefore not as

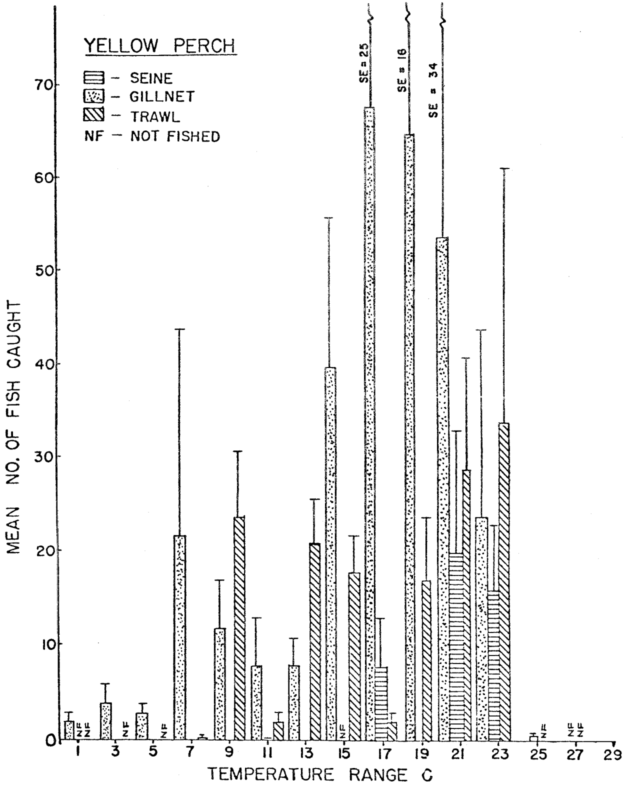


FIG. B33. Mean catch and standard error of yellow perch at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

frequently observed in open parts of the lake. Perch were seen most frequently during the warmest period of the diving season, June through August, which correlates with periods of maximum abundance (Table B6).

Differences between diurnal and nocturnal behavior of these fish were noted. During the day, perch were seen to be actively swimming throughout the lower half of the water column in the areas near the crib structures. Fish did not rest on or swim along the bottom riprap. Schooling behavior was not noted, although dispersal was uneven. At night, perch in the area of the structures were inactive, either resting on the bottom or suspended in the bottom 2-m portion of the water column. Fish could be captured barehanded. More fish were observed at night (maximum observation 100) than during the day (maximum observation 10). The heightened incidence of observance nocturnally may be due to the fact that the fish are less easily frightened from the area when they are inactive.

During a night dive on 17 June 1973 in the area adjacent to the south intake structure, 60-75 (150-250 mm) and 15-20 (250-350 mm) perch were observed over a 71-min period. Water temperature was 18.5 C. More perch were seen during this dive than on any other occasion, the majority were inactive or resting on the riprap surrounding the intake structure. Spawning activity was not observed.

Work from Neill (1969) on Lake Monona, Wis., which receives a heated effluent, showed that perch were taken most often during the day with electro-shocking gear. Neill described perch as heat-intolerant species which seldom occupied the outfall area. He found through mark and recapture experiments that perch did not remain in the effluent for very long and that yellow perch were more abundant in the reference than in the effluent area.

In the Cook Plant vicinity considerable value is placed on yellow perch by local sport fishermen. During the summer, local residents fish for perch from boats and piers at St. Joseph and along the lake shore. In summer of 1974, on some days 10-20 boats were observed off the Cook Plant, the fishermen probably seeking yellow perch. Apparently the underwater structures and riprap attract yellow perch which in turn concentrate fishermen in the area.

Trout-Perch

Trout-perch are widely distributed in lakes and streams throughout central and northern North America (Scott and Crossman 1973). In the United States it is a common native species in the Great Lakes but is relatively rare further south. Its commercial and sport fishing value is negligible. Although of little economic importance, trout-perch are a significant component of the aquatic food chain. In some northern lakes they are important forage fish for lake trout and walleye. Because trout-perch feed at night in the shallows and move into deeper water during daylight, they may serve as nutrient transporters (McPhail and Lindsey 1970).

As with most forage fish species, definitive works on trout-perch are rare. Kinney (1950) made the first extensive investigation of age, growth, reproduction and food habits of trawled trout-perch in western Lake Erie. While investigating the biology of a cestode, Lawler (1954) made observations on reproduction and age of stream-trapped trout-perch from Heming Lake, Manitoba. Magnuson and Smith (1963) performed the most comprehensive study to date of trout-perch from Lower Red Lake, Minn. Age, growth, population structure and reproduction of 10,511 seined and trawled fish were intensively studied. From fish collected by trawling, Bostock (1967) studied the ecology of trout-perch from Lake Superior. House and Wells (1973) described age composition, growth rate, fecundity and spawning season of trawled trout-perch from southeastern Lake Michigan. Although much is known on the life history of this fish, more studies are needed on relationships between trout-perch and other species in the Great Lakes as well as information on spawning habits and distribution of larval trout-perch.

Statistical Analyses of Trout-Perch Catch

Trawls. Results of the ANOVA revealed highly significant ($P < 0.01$) main effects due to MONTH, DEPTH and TIME of day (Table B29). Differences between areas was not significant (0.01 level). The test statistic was very close to zero, indicating very little difference between study areas. The value of this finding is reduced, however, since AREA entered into interactions with MONTH, DEPTH and TIME of day. However, it is probable that trout-perch populations are similar at the Cook Plant and Warren Dunes areas. This attests to the homogenous quality of the inshore waters along the coast of southeastern Lake Michigan and helps establish a baseline for detecting population differences between trout-perch at the control site and the plant site once the Cook Plant becomes operational.

In the ANOVA there were significant ($P < 0.01$) second-order interactions among MONTH, AREA and DEPTH and among MONTH, AREA and TIME (day-night) (Table B29). Since higher-order interactions tend to mask main effects, it became necessary to examine the two interactions in detail.

Both interactions are inextricably linked to the following factors: 1) general inshore spawning activity commencing in June, 2) climatic (physical) factors occurring during sampling, such as an August upwelling, and 3) high variability inherent in trawl samples. Area effects in the interaction terms are the most difficult to explain. Conceivably, different behavior patterns are occurring between trout-perch at the Cook Plant and Warren Dunes, but unless different physical substrate characteristics are present or a distinct biological pattern becomes apparent in subsequent sampling, it is unwarranted to consider that there are actual differences between study areas.

The MONTH x DEPTH x AREA interaction (Fig. B34) is probably the result of high June catches at the 9.1-m stations, which were probably somewhat related to spawning although spawning is thought to continue through July. After June, 9.1-m catches at Warren Dunes were either equal to or greater than 6.1-m catches. Catches at Cook 6.1-m stations, probably partially

TABLE B29. Summary of analysis of variance for trout-perch caught in trawls in the Cook Plant study area from June through October 1973.

Source of variation	df	Adjusted mean square[1]	F-Statistic	P
AREA	1	.01518	.16	NS[2]
MONTH	4	1.05937	11.19	<.01
DEPTH	1	2.98711	31.56	<.01
TIME of day	1	8.30979	87.79	<.01
AxM	4	.38472	4.06	<.01
AxD	1	.00372	.04	NS
AxT	1	.31215	3.30	<.01
MxD	4	.77185	8.15	<.01
MxT	4	.79715	8.42	<.01
DxT	1	4.38239	46.30	<.01
AxMxD	4	.45518	4.81	<.01
AxMxT	4	.49765	5.26	<.01
AxDxT	1	.00390	.04	NS
MxDxT	4	.12307	1.30	NS
AxMxDxT	4	.31117	3.29	<.05[3]
Within cell error	39[4]	.0946524		

[1] Mean squares were multiplied by harmonic cell size/maximum cell size (n_h/N = 0.976) to correct for two missing observations where the cell mean was substituted.

[2] Not significant (P>.05).

[3] Not significant (.01 <.05).

[4] One degree of freedom was subtracted to correct for one missing observation where the cell mean was substituted.

Area x Month x Depth Interaction

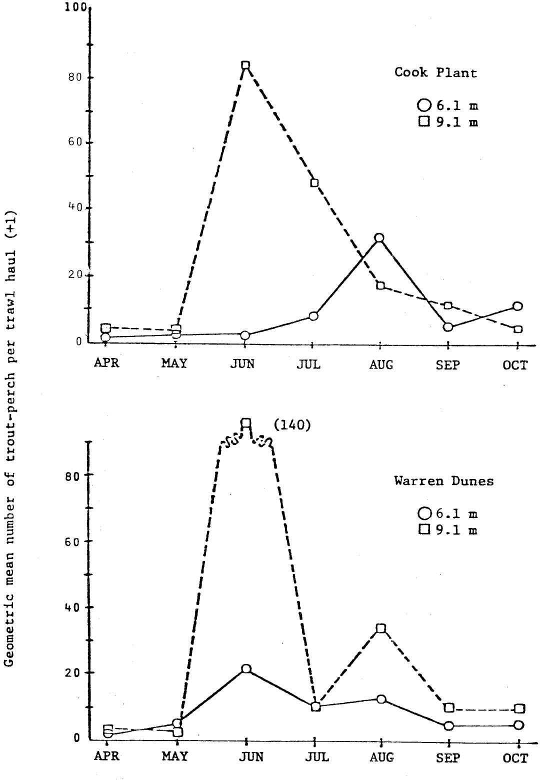


FIG. B34. Geometric mean number of trout-perch caught in duplicate trawl hauls April through October 1973 at 6.1-m and 9.1-m stations in the Cook Plant study areas. April and May data were excluded from ANOVA.

responsible for the interaction, were greater than corresponding 9.1-m catches in 2 of the 4 remaining months. Biological reasons for this are unclear and perhaps non-existent as it is suspected that inherent variability in trawl catches is responsible. An upwelling in August, when higher 6.1-m than 9.1-m station catches were recorded, may also be a consideration. Clearly high catch at 6.1 m in August at the Cook Plant accounts for AREA entering the interaction.

In examining the data plot for the MONTH x TIME of day x AREA interaction (Fig. B35) it was found that trout-perch were with one exception caught in greater numbers during the night than during the day at the two areas. The one exception, and probable cause for the interaction, was that during August a greater day catch, when compared to night catches, was made at the Cook Plant. Increased inshore abundance during the day in August might be explained if temperature related movements of fish occurred in response to the August upwelling, resulting in an inshore concentration of fish.

Pinpointing exact causes of higher-order interactions is difficult. The preceding interpretations should be regarded as a coupling of statistical significance and our knowledge of the biology of trout-perch. In this sense, explanation of interactions involves much speculation. Analysis of variance does, however, serve as a valuable aid in delineating the biology of fish in the study areas and identifying weak points in our knowledge of individual species. Fortunately we also have complimentary information from gillnet catches and beach seining.

Gillnets. Non-replicate gillnet catches were not amenable to parametric statistical analysis, and consequently were analyzed using nonparametric techniques (Table B30). No statistically significant differences were found between depths nor between areas nor, surprisingly, among months using non-parametric tests (Table B30) which may be a result of many zero catches--percentage zeros ranged from 30-59. For trout-perch at least, nonstatistical analysis, as follows, is more appropriate in understanding trout-perch biology.

Night gillnet catches of trout-perch were uniformly higher than day catches at all stations and for every month between June and October (Fig. B36). The most noticeable difference between trawl and gillnet catches was that peak numbers of trout-perch occurred in July gillnets, whereas maximum catch in trawls occurred in June. Since gillnets are selective for mature individuals and gonad condition indicated spawning was occurring, the high July inshore 6.1-m gillnet catches may be coincident with peak spawning period. There was another local maximum catch of trout-perch from the 6.1-m depths in October, possibly related to weather conditions. Prior to the sampling period a 5-day storm had occurred in the area, which may have affected distribution and movement of fish both during and after the storm.

Seines. Although the experimental design for seining was intended for statistical analysis, the large number of zero catches (Fig. B37) due to spatial ranging of trout-perch prohibited parametric analysis. Thus a

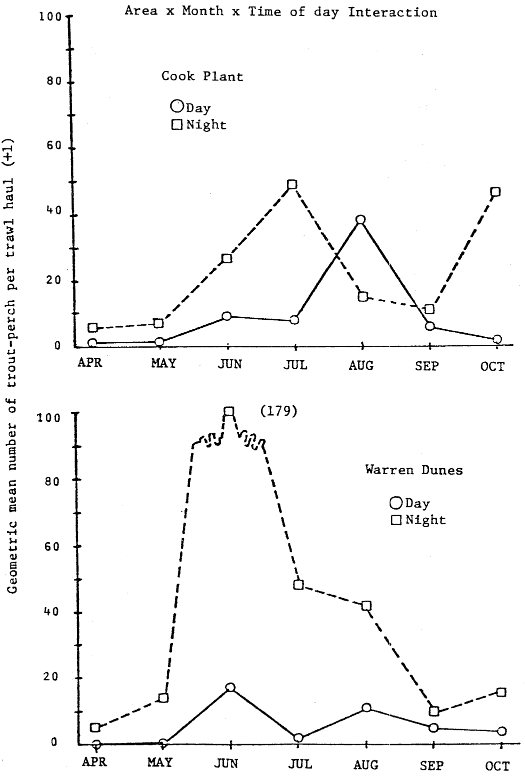


FIG. B35. Geometric mean number of trout-perch caught in duplicate trawl hauls during the day and night, April through October 1973, at the Cook Plant and Warren Dunes, southeastern Lake Michigan. April and May data were excluded from the ANOVA.

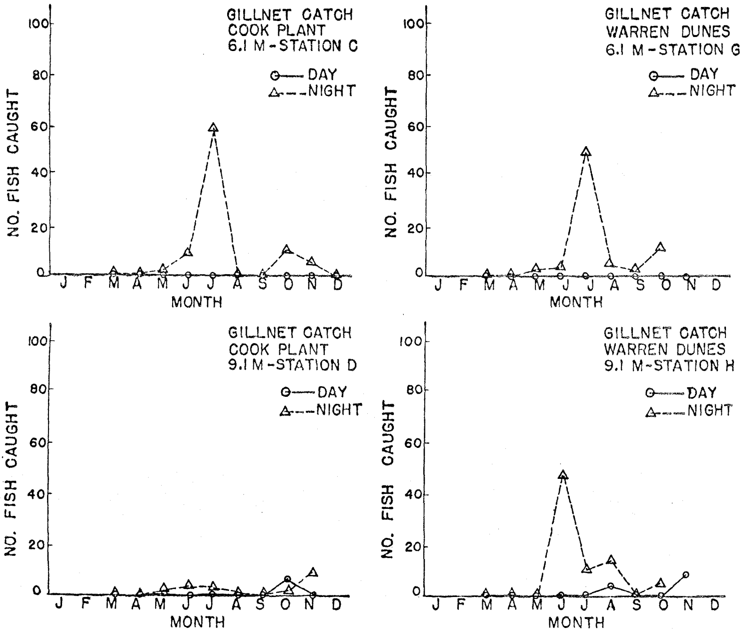


FIG. B36. Number of trout-perch caught in gillnets set during day and night once per month February through December 1973 in southeastern Lake Michigan.

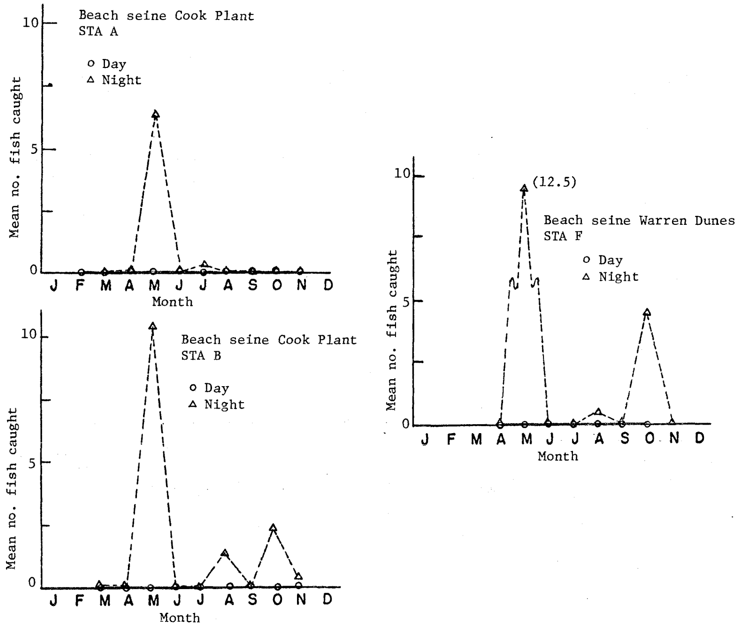


FIG. B37. Mean number of trout-perch caught in seines fished during day and night once per month February through November 1973 in southeastern Lake Michigan.

TABLE B30. Summary of nonparametric analyses of trout-perch caught in standard series gillnets from Cook Plant study areas April through October 1973. NS = not significant.

Factor (and levels)	df	Kruskal-Wallis statistic Value	P	Mann-Whitney U statistic Value	P
Month (May-Oct)	5	3.3460	.6468 NS	----	----
Depth (6.1 m, 9.1 m)	1	.60421	.4370 NS	482.00	.4086 NS
Area (Cook Plant, Warren Dunes)	1	.67204	.4123 NS	442.50	.3834 NS

nonparametric Kruskal-Wallis test was used to test for differences between stations and study areas; no significant difference was found (Table B31). Insufficient data existed to test differences between months.

Seasonal Distribution by Age-Size Class

Length-frequency histograms for trout-perch caught in standard series nets were compiled by gear type (Figs. B38, 39, 40). These histograms must be examined in total to delineate movement patterns because of size selectivity of the various gear. We can discuss with confidence only the seasonal ranging of young-of-the-year, yearlings and adults. Beyond this categorization inferences become less valid.

Young-of-the-Year. YOY with a modal length of about 25 mm first appeared in September sampling (Fig. B40). Because the majority of spawning activity probably occurred from June to August, although some spawning may have occurred in May and September (Table B32), YOY trout-perch should have been taken in samples before September. Either YOY were not present in the study area from June through August or, as appears to be the case, fish were present and our sampling gear did not collect them. Assuming YOY trout-perch were present in the study area before September, probably the mesh of the trawl net was too large to retain small specimens. Another possible explanation for the failure to capture YOY prior to September may be that their distribution is very spotty. Also, we suspect that most or all life stages of trout-perch are associated closely with the bottom. YOY were not captured by seining, indicating that at this life stage utilization of the beach zone does not occur. In October many YOY, 25 to more than 40-mm size range, were caught by trawling (Fig. B40), which again lends support to a July spawning peak. YOY were captured during the day and night, and apparently do not exhibit a tendency towards extensive nocturnal horizontal movements as do adult fish. By November YOY had presumably moved offshore as did the bulk of the adult trout-perch population.

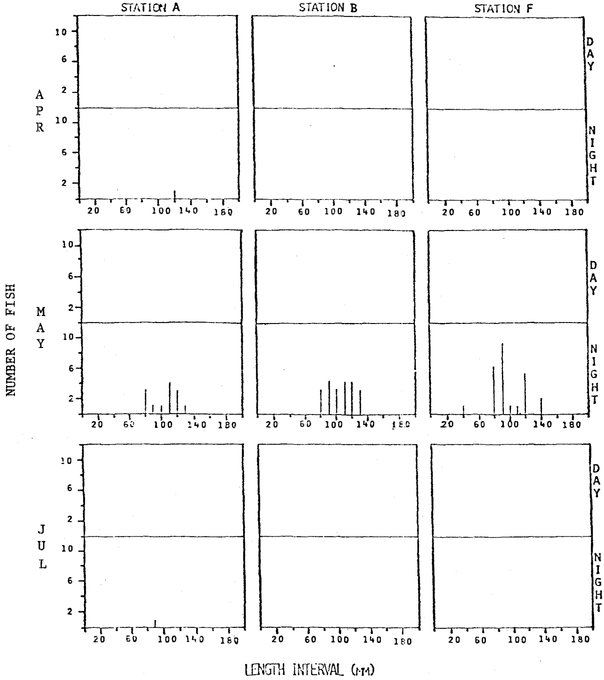


FIG. B38. Length-frequency histograms for trout-perch caught in standard series seining during 1973 in the Cook Plant study area of southeastern Lake Michigan. ND = no data.

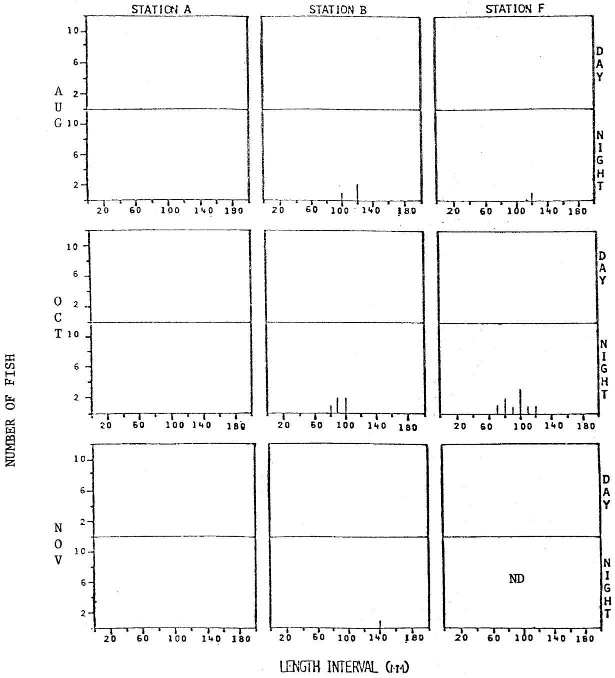


FIG. B38 continued.

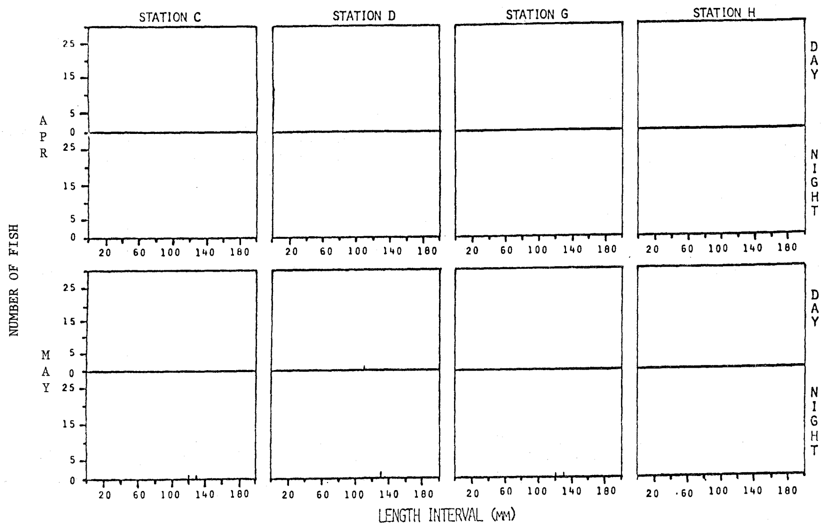


FIG. B39. Length-frequency histograms for trout-perch caught in standard series gillnetting during 1973 in the Cook Plant study area of southeastern Lake Michigan. ND = no data.

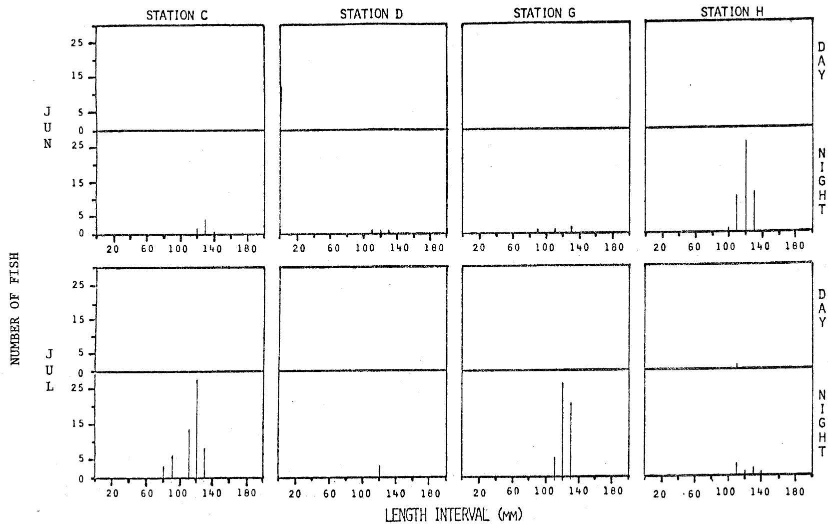


FIG. B39 continued.

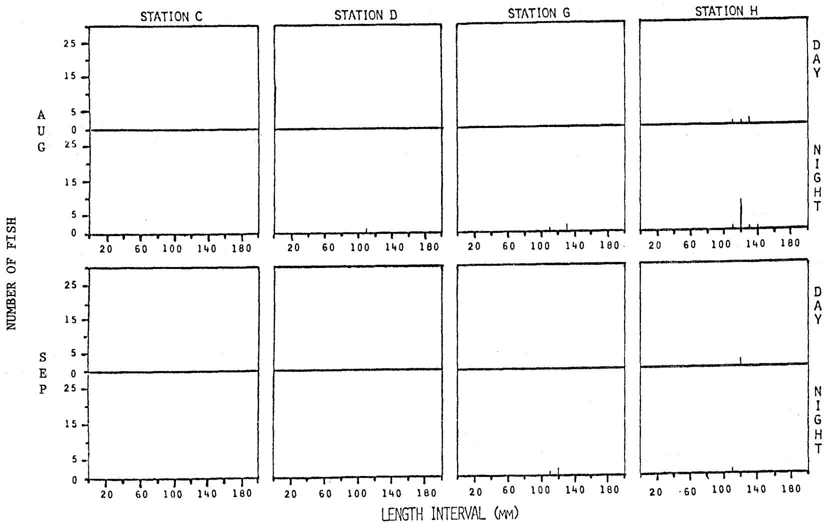


FIG. B39 continued.

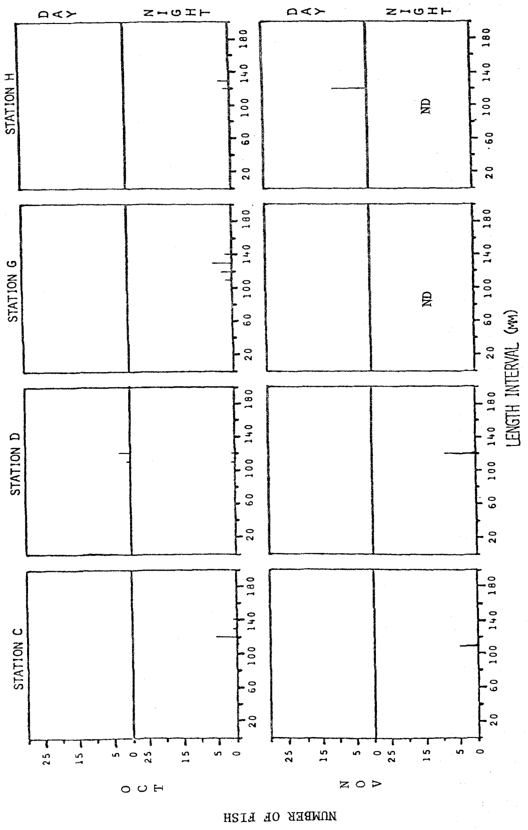


FIG. B39 continued.

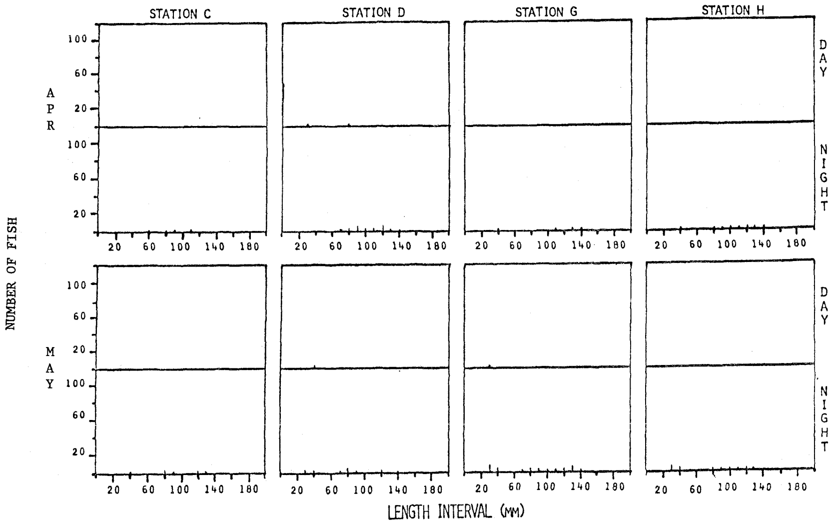


FIG. B40. Length-frequency histograms for trout-perch caught in standard series trawling during 1973 in the Cook Plant study area of southeastern Lake Michigan. ND = no data.

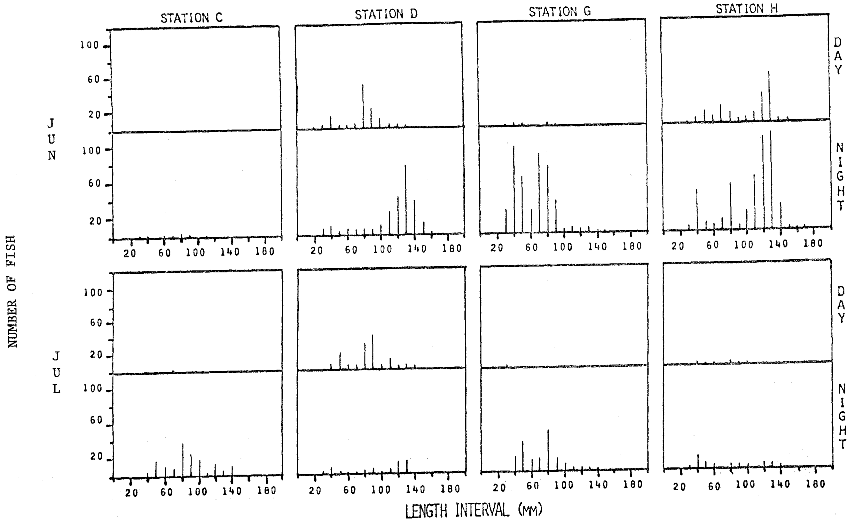


FIG. B40 continued.

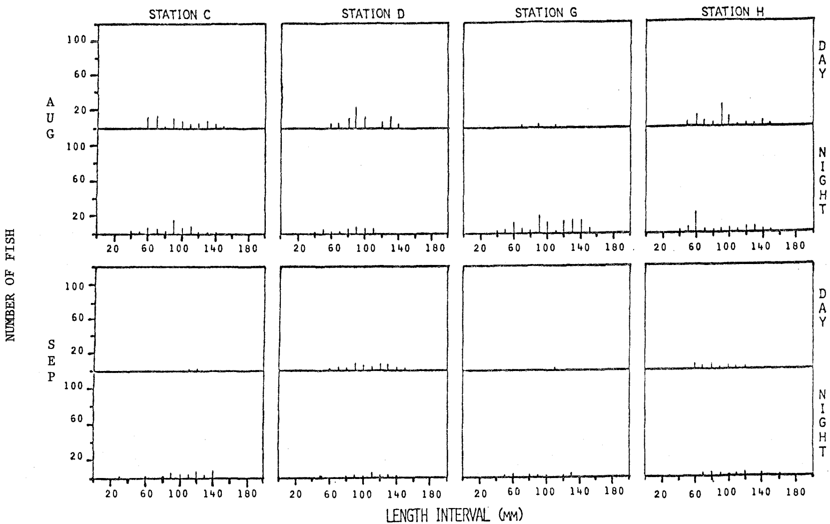


FIG. B40 continued.

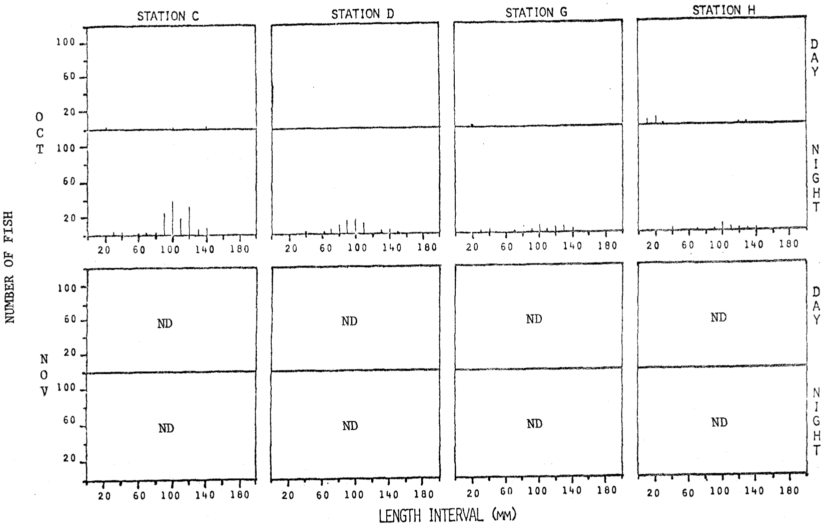


FIG. B40 continued.

TABLE B31. Summary of nonparametric analysis of trout-perch beach seine data collected from Cook Plant study areas 1973. NS = not significant.

Factor (and levels)	df	Kruskal-Wallis statistic Value	P
Stations (A, B, F)	2	.20192	.9040 NS
Area (Cook Plant, Warren Dunes)	1	.11538	.7341 NS

No trout-perch larvae, fish less than 25 mm, were captured during 1973 (see Sec. C). Again assuming that spawning occurs in the study area, the suspected benthic behavior of these larvae and our failure to sample effectively at this stratum may explain why no larvae were captured. Benthic sled tows initiated in 1974 should help to verify or disprove whether trout-perch larvae are present in the area and whether demersal behavior is occurring.

Yearlings. Yearling trout-perch first appeared in limited numbers in April trawl samples (Fig. B40); modal length was approximately 40 mm. Additional yearlings were collected in May and June at which time modal length was more than 45 mm. By July this length had increased to 50 mm, which compares favorably to findings of House and Wells (1973), who calculated total length of southeastern Lake Michigan trout-perch to be 49 mm at the end of their first year of life. Growth of yearlings from Lake Michigan appears to be slower than yearlings studied in Lower Red Lake, Minn. by Magnuson and Smith (1963), whose calculated average lengths for females and males in June (time of annulus formation) was 51.4 and 50.8 mm respectively.

Yearlings were caught in April and May more frequently during night than day trawling (Fig. B40), but differences between numbers were not as pronounced as with adult trout-perch, which were caught at night. Evidently yearlings do not migrate beyond the 9.1-m contour as do adults. Only one yearling was caught by beach seining in May (Fig. B38), indicating that yearlings rarely enter the beach zone. We concluded that yearlings in the spring during both day and night are distributed from 2 to at least 9 m.

During June, July and August, differences between day and night catches of yearlings were more pronounced, with greater catches occurring at night. Apparently at this stage yearlings are following the nocturnal migrational pattern exhibited by adults to a greater extent than in April and May. In April and May there was little difference in catches between stations; however in June, July and August catches of yearlings at the 6.1-m stations were greater at night than during the day. The obvious pattern is that yearlings remain at the 9.1-m contour and probably deeper water during the day and migrate inshore at night to the 6.1-m contour and possibly even shallower water. They must not migrate into the beach zone at night since no yearlings were caught by night beach seining. Reasons for this nocturnal migration

TABLE B32. Monthly gonad conditions of trout-perch as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.			1	1			4	14	86	1	
Mod. dev.				5	3	1	38	10	38	1	
Well dev.			18	65	198	117	55	12	1		
Ripe-running				3	1	7					
Spent					53	53	71	34	9	1	
					Males						
Poorly dev.			2	1	4		6	22	55	3	
Mod. dev.		1	10	19	9		21	14	16	1	
Well dev.			10	47	111	56	53	6			
Ripe-running			1		1						
Spent					20	33	34	21	1		
					Unable to distinguish						
			1	2	11	11	9	3	4		

are probably related to feeding behavior; future analysis of stomach samples may help clarify this behavioral pattern. In September a few yearling trout-perch were caught at 9.1-m stations during the day and at all stations at night. By October no yearlings were caught during the day, but many were caught with adults at 6.1 and 9.1-m stations, indicating that inshore nocturnal migrations from farther out were still occurring in October.

Adults. Due to considerable variation of length within each age class (Bostock 1967), ages of trout-perch are generally difficult to determine accurately. From age-group length distributions determined by House and Wells (1973), it appears that fish 80-140 mm long could range from 2-7 yr old. As a first approximation of age-classes, we compiled a composite length-frequency histogram consisting of standard series and supplementary nettings, and examined it by month (histogram not shown). Local modes of trout-perch lengths appeared to corroborate the findings of House and Wells (1973). Two- and 3-yr olds are probably 50-100 mm total length. Fish 100-140 mm are probably 4-6 yr old. Trout-perch from 140-170 mm may be 7-9 yr old. Trout-perch undoubtedly grow to greater lengths in southeastern Lake Michigan than has been reported elsewhere in the Great Lakes. The largest specimen House and Wells (1973) captured was a 152-mm female. Scott and Crossman (1973) indicate an identical maximum length for a specimen

from Lake Ontario. In the southern boundaries of their range, trout-perch grow to their greatest reported lengths, occasionally to 200 mm (McPhail and Lindsey 1970). Our largest specimen was a 168-mm (T.L.) female weighing 38.8 g. Several other fish were well over 150 mm. The large size attained by trout-perch in southeastern Lake Michigan may be related to lack of predation. Stomach contents of large salmonids captured during our fishing efforts seldom contained trout-perch.

No trout-perch were caught during our limited fishing efforts in January and February (Table B6). Like alewife, trout-perch sought deeper waters in Lake Michigan during winter months. Wells (1968) found most trout-perch at 37 to 61 m in winter. Bostock (1967) found trout-perch in Lake Superior were confined to waters deeper than 64 m during the winter and early spring. Our catches indicated they were still scarce inshore in March.

In April, adult trout-perch began to appear in about equal numbers in our catches at both study areas (Fig. B40). All size classes were represented. Apparently the total population migrated inshore in spring, in contrast to some other species (e.g. alewife) where larger individuals migrated inshore first. Most trout-perch were caught at night at 9.1 m. An analogous pattern continued into May, but overall catch was higher. Night catches continued to be higher in both study areas but there was no apparent preference for either 6.1 or 9.1-m depths. Evidently fish were outside the 9.1-m contour during the day in April and May and migrated inshore at night. May was also the first month of the year when trout-perch were captured in the beach zone, during night seining (Fig. B38). At night apparently at this time of year these fish extended their range into the beach zone, which was possibly associated with feeding behavior or thermal preferences. Scott and Crossman (1973) indicate that trout-perch move into shallows of lakes to feed in the evenings and retreat to deeper water with approach of dawn.

June marked the first major influx of adult trout-perch into the inshore area (Fig. B40). Very high night catches characterized the yield at each station with the exception of the 6.1-m station at the Cook Plant. All size classes were represented in the catches, indicating that a complete cross-section of the adult trout-perch population was inshore at this time. Day catches in June were relatively large compared with previous months' catches, and subsequent gonad examination (Table B32) suggested that initiation of spawning activity may have been responsible. Ripe adults were found in the study area from May through August (Table B32), and spent adults were found in increasing numbers from June through August. House and Wells (1973) found trout-perch spawning from late June to September in southeastern Lake Michigan. They apparently spawned later in southeastern Lake Michigan in 1973 than has been reported from other areas: Heming Lake, Manitoba (May--Lawler 1954); Lower Red Lake, Minn. (May to August--Magnuson and Smith 1963); Lake Erie (May to July--Fish 1932). Kinney (1950) found trout-perch spawned from June to August in Lake Erie, later than reported by Fish (1932). Although ripe fish in an area does not necessarily prove spawning is occurring, presence of many ripe and several ripe-running specimens in our samples indicates that some spawning must have occurred in study areas. General accounts from the literature (McPhail and Linsey 1970; Scott

and Crossman 1973; Magnuson and Smith 1963) revealed that spawning takes place at night in shallow water (0-1.3 m) in slow moving streams or along lake beaches. Eggs are small, 1.5 to 1.9 mm in diameter, adhesive, and hatch in about 1 week. House and Wells (1973) found that sexual maturity is attained by few 1-yr old fish, 84% of 2-yr old males, 50% of 2-yr old females, and all 3-yr olds. Trout-perch mortalities of dieoffs following spawning have occasionally been reported (Magnuson and Smith 1963), however we observed none in our study area to date.

In July, differences in catch between depths and areas were not as great as in June, and nocturnal behavior was again suggested. Day catch exceeded night catch for the first and one of the only times at the Cook Plant in August, whereas the usual pattern of greater night catch was true for Warren Dunes. Considerably more trout-perch were caught during the day at the 6.1-m Cook station than in any other month at that station. This apparent irregularity appeared to be caused by an upwelling which occurred during trawling. It is hypothesized that this cold water mass "forced" fish into shallower water. Effects of the upwelling were apparently greatest at the Cook Plant, since more fish at Warren Dunes were caught at 9.1 m than at 6.1 m. (See Seibel and Ayers 1974 for a discussion of upwellings in the study area).

Number of adult trout-perch caught in September decreased noticeably from summer peaks. Fish had apparently begun to move into deeper water. The familiar pattern of highest night catches in deeper, 9.1-m, waters returned.

In October, as in most past months, the same general pattern of heightened nocturnal activity continued. October night catches of trout-perch at both study areas were much higher than their respective nighttime September yields. Presence of fish in the seine catch at night indicated trout-perch were again utilizing the beach zone as they did in May.

Very few fish were caught in November and December; however, no trawling was performed and possibly a few more would have been caught if trawling had been done. Wells (1968) found the majority of trawled trout-perch were in water deeper than 13 m in November, although a few fish were caught at 5.5 and 9.1 m. Apparently by November the majority of the trout-perch population in the study area had migrated to deeper water for the winter. The fall migration was evidently somewhat prolonged during 1973 in our study area. Wells (1968) captured all of his October specimens beyond the 9.1-m contour in southeastern Lake Michigan in 1964 when bottom temperatures were 11.7 to 12.3 C, while we caught large numbers of trout-perch when bottom temperatures were 13.7-15.7 C in October. By November bottom temperatures were below 12 C in our study area and we caught few trout-perch. Bostock (1967) found the return to deeper water occurred by late September and early October in Lake Superior.

Temperature-Catch Relationships

Any conclusions from our study about temperature preference of trout-perch must be cautious generalities for the following reasons: 1) extensive

trawling by Wells (1968) suggests that except for June through August the bulk of the trout-perch population resides outside the 9.1-m contour, 2) preferred temperatures may reflect spawning temperature preferences rather than temperatures most often selected during the non-spawning period of the year. Most of our trout-perch were caught in trawls when water temperature was from 14-20 C (Fig. B41); peak catch occurred between 16-18 C. This corresponded well with the upper range of temperature preferences, 10-15 C, found by Wells (1968).

Other Considerations

The large size attained by trout-perch and their abundance in the study area is thought to be related to lack of predation. We seldom found trout-perch in stomachs of piscivorous fishes--yellow perch, northern pike, lake, rainbow and brown trout, chinook and coho salmon. However, available literature reveals that most of the above species do prey on trout-perch in other habitats (Lawler 1954; Magnuson and Smith 1963; Scott and Crossman 1973). Evidently extremely abundant alewives supply piscivores in our study area with an ample food supply and act as a buffer species for the trout-perch at least. Alewives were a common and apparently preferred or available prey of the piscivores in our study areas. Since trout-perch are abundant in the study area, we hypothesize that the demersal behavior of trout-perch makes them a less available prey than the ubiquitous alewife. A similar situation may exist with spottail shiners, which are also extremely abundant in the study area, yet seldom preyed upon. Absence of predation by lake trout on trout-perch is difficult to explain, since lake trout in the study area preyed upon other bottom-dwelling fish such as sculpins. If for some reason alewife numbers were to decrease drastically in southeastern Lake Michigan, spottails and trout-perch might serve as food for lake trout.

Walleye, which prey on trout-perch and are usually found in waters with trout-perch, were not found in the study area; one walleye was captured in 1972. Magnuson and Smith (1963) found walleye to be the most significant single predator on trout-perch in Red Lakes, Minn. Scarcity of walleye in the study area is an enigma. Possibly absence of spawning areas prevents this species from developing a population capable of sustaining itself. We suggest that it might be advisable to stock walleye in southeastern Lake Michigan, where sufficient prey exists for this species. Although there is presently a stocking program of other piscivores, lake trout and salmon, in Lake Michigan, addition of another valuable sport fish may be warranted in view of the abundance of food.

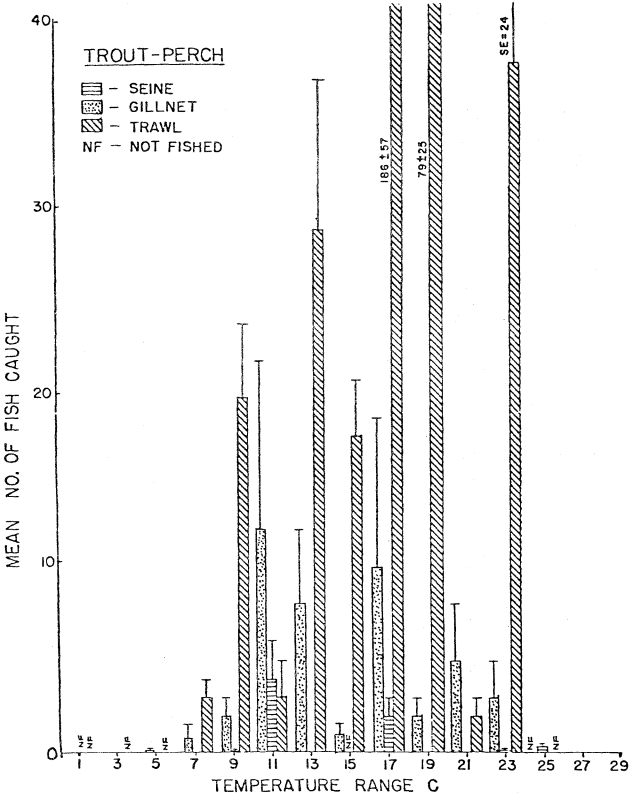


FIG. B41. Mean catch and standard error of trout-perch at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

LESS ABUNDANT SPECIES

Johnny Darter

Johnny darters occupy a unique position among species captured in the Cook Plant vicinity, being the only darter captured as well as being very abundant--sixth among all sampled. Darters convert, through feeding, a large quantity of benthic organisms to fish flesh, sometimes serve as food for larger fish and are important ecological links in community food chains. In the Great Lakes, johnny darters are usually associated with inshore waters, although one specimen was taken in 46 m (138 ft) of water (Scott and Crossman 1973).

Spawning of darters occurs sometime in spring (Scott and Crossman 1973), and spawning in the plume of a hydro plant in Ontario was noted by the above authors as early as 26 April 1935 (year of study). In southern Quebec, gravid adults were caught only during late May; June was listed as the spawning month for johnny darters in Lake Nipigon, Canada. Our data (Table B33) indicate May and June as months when those in the vicinity of the Cook Plant spawn. During May, 17 out of 18 females were gravid; in June, 13 of 23 females captured were gravid, 5 were spent and 5 others were

TABLE B33. Monthly gonad conditions of johnny darters as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.			1	1			1		9		
Mod. dev.			2		5		1	1	4		
Well dev.			4	17	13	1					
Ripe-running											
Spent					5	4	8	2			
					Males						
Poorly dev.				1					4		
Mod. dev.			1	9			2	1	2		
Well dev.			2	5	4	1					
Ripe-running						3	3	2	1		
Spent											
					Unable to distinguish						
				1	4	7	9	2	4		

less developed. Spawning behavior of johnny darters in southern Michigan streams has been described by Winn (1958). Males move to spawning grounds in about April, select and clean the underside of an appropriate rock as a nesting site and the female enters. Both fish turn upside down beneath the rock and eggs are subsequently laid and fertilized. Males guard the eggs and hatching occurs within 5-8 days at incubation temperatures of 22-24 C. Fish (1929) describes various stages of larval development. Scott and Crossman (1973) cite 69-mm long (T.L.) specimens as approaching maximum size for the species; our largest specimen was 76 mm.

In 1973, 207 johnny darters were captured only from April through October in standard series fishing. June was the month of maximum catch, 58, they were never caught with gillnets, and only seven were captured in seines, all at the Cook Plant. The remaining 200 fish were caught in trawls. Darters appeared to be more susceptible to trawling during the night (151 caught) than during the day (56 caught). More were captured at 6.1-m stations during May, June and July than at 9.1-m stations. The largest was a 76-mm male (3.4 g) taken in October. The smallest, taken in September, was 19 mm (0.01 g) and was probably a YOY or a possible yearling (Table B34). Johnny darters from 40-70 mm dominated the catch.

Darters captured in beach zones were taken at water temperatures between 16 and 24 C (Table B35). Trawl data, representing the largest catches, showed that darters were caught between 6 and 22 C with largest catch occurring between 20-22 C.

Johnny darters were observed upon numerous occasions by SCUBA divers working in the vicinity of the Cook Plant intake and discharge crib structures. Along with sculpins, darters were the most consistently diver-observed species in areas of riprap examined. They were not commonly

TABLE B34. Length-frequency distribution of johnny darters caught in standard series nets during 1973 in Cook Plant study areas.

Midpoint of length interval (mm)	APR	MAY	JUN	JUL	AUG	SEP	OCT	Totals
20						1		1
30		3	4		1	3	4	15
40	4	10	22	4	4	1	3	48
50	1	6	21	8	5	1	3	45
60	4	18	10	5	14	3	13	67
70	4	10	1		7	2	6	30
80							1	1
Totals	13	47	58	17	31	11	30	207

TABLE B35. Temperature-catch relationships of johnny darters inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—							—	.3±.2	.2±.2	.1±.1	.1±.1		
G													—	—
T	--	—	--	.9±.3	2±.5	2±.7	2±.6	1±.3	2±1	1±.5	5±3		—	—

seen in areas outside the riprap, that is normal sand bottom typical of this area of Lake Michigan. It is presumed that riprap may present a habitat more suitable to darters than the exposed shifting sand bottom.

Darters were noted to be solitary by nature and demersal in habitat. Seldom were they observed to swim more than several feet from a given location unless continuously disturbed. Most frequently they were observed resting on top of the riprap or occasionally on top of the structures. These fish appear to be more active during the day than at night, since both activity level and number of individuals observed increased diurnally.

White Sucker

White or common suckers are usually found in warm shallow lakes or bays, and tributaries of larger rivers (Scott and Crossman 1973). Although restricted to North America, they are common throughout Canada and the United States. They are found throughout the Great Lakes and are associated with the littoral zone of Lake Michigan.

The moderately important commercial fishery in Lake Michigan has been located primarily in Green Bay and the northern portion of the lake (Wells and McLain 1973). Commercial production of suckers, the majority white suckers, averaged 9.5 x 10^5 kg (2.1 million lb) in 1889-1949, 3.5 x 10^5 kg (766,000 lb) in 1950-60, 1.5 x 10^5 kg (337,000 lb) in 1961-68 and nearly 4.5 x 10^5 kg (1 million lb) in 1970 (Wells and McLain 1973). Although the flesh is edible, market demand has not been high. Sport fishing for white suckers in limited; young suckers are utilized as bait and hatchery food for game fishes.

Because white suckers are abundant in some lakes and streams and are frequently found in close association with valuable salmonids, there have been several investigations on their biology and ecology. Some of the more

extensive studies are Campbell (1935), Hayes (1956), Bassett (1957) and Geen et al. (1966). Stewart (1926) and Schneberger (1972) presented general accounts of white sucker biology. White suckers are common throughout Lake Michigan, but to our knowledge, there are no studies of the ecological relationships of this species in the lake.

White suckers were the seventh most abundant fish taken in our standard series collections during 1973 (Table B6). Most were captured in gillnets, especially at night (Tables B7, 8). Gillnets are apparently an effective means of collecting white suckers, since larger fish effectively avoid the trawl and seine. Relatively higher night catches agree with known nocturnal habits of this species; western white suckers move inshore at night and offshore during the day (Hayes 1956). Diurnal inshore-offshore migrations have been documented by others as well, and Hayes (1956) associated these movements with feeding behavior.

During 1973, 281 white suckers were collected through our total fishing efforts (Table B36). During colder months, November, December and February,

TABLE B36. Monthly length-frequency distributions of white suckers caught during 1973 in southeastern Lake Michigan at the Cook Plant study site. Catches from all gear are pooled.

Length interval (mm)	Feb[1]	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Totals
0–44											
45–94				1	3						4
95–144				1	6	3					10
145–194					1	4	1				6
195–244				1	1	1		1			4
245–294				2			2	1	5		10
295–344		2	1	6	3	3	4	4	8		31
345–394		3	1	1	2	2	9	12	7		37
395–444		5		9		7	11	9	6	1	48
445–494	1	23	5	3	9	6	10	13	2		72
495–544	1	6	2	2	5	6	5	10	1	3	41
545–594		1			3	3	5	4			16
595–644								1	1		2
Totals	2	40	9	26	33	35	47	55	30	4	281

[1] No fish were caught in January and December.

few fish were caught, suggesting that cold-water temperatures limit their activity or they move offshore. Numbers caught in spring, summer and fall were similar. Apparently this species stays inshore during these seasons, as numbers caught did not fluctuate greatly. Low catch in April may be related to spawning activities elsewhere.

Our gonad data (Table B37) indicate that white suckers probably spawn in late March, April and May. They are known to breed in April and early May in southern Michigan (Reighard 1920). Spawning occurs from March through early August in a variety of habitats; the exact time can vary from year to year, usually depending upon water temperatures (Carlander 1969). Other studies indicate that spawning occurs when water temperatures reach 7.2 C (Schneberger 1972) to 10 C (Geen et al. 1966; Scott and Crossman 1973). In southeastern Lake Michigan during 1973 these temperatures were attained in mid-April.

White suckers spawn in tributaries to lakes (Bassett 1957; Geen et al. 1966) and in shallow lakes (Hayes 1956; Scott and Crossman 1973). The low number caught in April may indicate that suckers from Cook Plant study areas were spawning in streams or elsewhere in the lake.

While large adults were caught during most months, juveniles were

TABLE B37. Monthly gonad conditions of white suckers as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.		1					17	8	6		
Mod. dev.							2	11	3	5	
Well dev.	1	26	1	2					6	3	
Ripe-running		3									
Spent			4	7	16	12	7	4			
					Males						
Poorly dev.		1		1			8	3	2		
Mod. dev.	1	1	1	2			7	11	2		
Well dev.		7		1				11	1	2	
Ripe-running											
Spent				4	3	8	3	4	3		
					Unable to distinguish						
				7	3	2	1	3	5	1	

caught only in summer. Smaller fish were probably 1-yr old or perhaps YOY's. Most white suckers caught were large, ranging from 400-600 mm in length, and from a comparison with published growth rates (Carlander 1969) these fish are estimated to be 6-11 yr old. Considerable overlapping of length ranges for various age classes can occur (Carlander 1969), and above associations are approximations.

Largest fish were caught in gillnets, smallest in seines (Table B38). Smaller suckers evidently utilize the beach zone to a great extent. A few larger suckers were captured in seines; these fish evidently make excursions into the beach zone.

More white suckers were caught at 6.1-m stations (C, G) than at 9.1-m

TABLE B38. Length-frequency distributions of white suckers caught during 1973 with gillnets, seines and trawls at eight stations near the Cook Plant, southeastern Lake Michigan.

Length interval (mm)	Fishing gear			Station								
	gillnet	trawl	seine	A[1]		B	F	C	D	G	H	E
0-44												
45-94			4			1	3					
95-144			10		2	4	4					
145-194	1		5		1	3	1	1				
195-244	1	1	2		2			1				1
245-294	10			3				3	2	1		1
295-344	29		2	2	2		1	11	2	6	5	2
345-394	32	1	4	4			1	10	8	10	1	1
395-444	44	3	1	4	2	2		9	9	16	6	1
445-494	67	2	3	27		1	1	10	3	13	16	
495-544	38	2	1	8		2	3	4	1	14	10	
545-594	15	1		2		1			1	4	9	
595-644	2			1					1			
Totals	239	10	32	51	9	14	14	49	27	64	47	6

[1] At station A, both seining and gillnetting were performed; first column is gillnetted, second is seined fish.

stations (D, H). Fish caught at shallow stations (6.1 m) tended to be smaller than those from deeper stations. Scott and Crossman (1973) indicated that older fish generally move farther offshore. However, we did not find this, as gillnetting at station E (21.4 m) produced only six fish (Table B38). These were smaller adults, which also suggests that the largest suckers may not range far out into the lake. Greater catches at stations G and H than at C and D indicate that larger suckers may be more abundant in the Warren Dunes than in the Cook Plant area.

Temperature-catch data (Table B39) suggest that adult suckers were caught most frequently in water of 12-16 C. Insufficient data exist to determine juvenile sucker preference.

Lake Trout

Lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*) are the two trouts native to Michigan waters. In Lake Superior a deepwater form commonly known as a siscowet occurs and is considered by some authors to be a subspecies (*Salvelinus namaycush siscowet*). Lake trout eggs have been successfully hybridized with brook trout sperm to produce fertile offspring called splake or wendigo.

Lake trout was the most valuable commercial species from 1890 to the mid-1940's. Between 1890 and 1911 annual catches from Lake Michigan averaged 3.7×10^6 kg (8.2×10^6 lb). After 1911 a general decline occurred with only intermittant increases in annual catch until 1945 when a precipitous drop occurred; by 1956 lake trout populations were probably extinct in Lake Michigan (Wells and McLain 1973). Presently, commercial fishing for lake trout is prohibited in Lake Michigan, however these fish support an active sport fishery with recent annual catches of more than 4.5×10^5 kg (1×10^6 lb) (Wells and McLain 1973).

TABLE B39. Temperature preference of white sucker inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	--				$.4 \pm .3$	$.3 \pm .2$		--			$.8 \pm .5$	$.5 \pm .3$		
G	$.8 \pm .2$	$.5 \pm .5$		2 ± 1	$1 \pm .5$	$1 \pm .5$	4 ± 1	$7 \pm .5$	$.8 \pm .5$	$.9 \pm .6$	$.6 \pm .4$	$.3 \pm .3$	--	--
T	--	--	--			$.1 \pm .1$	$.3 \pm .2$	$.04 \pm .04$		$.1 \pm .1$	$.2 \pm .2$		--	--

During winter, lake trout disperse widely throughout the lake; clipping and tagging information indicates they may range as far as 100 miles from their spawning grounds. In spring, fish may be found both in surface waters and inshore, but later move offshore remaining below the developing thermocline. Occasionally during summer lake trout make excursions to warmer water, but they exhibit an overall preference for temperatures of 10 C or less (McCauley and Tait 1970; Scott and Crossman 1973). The fish may also appear inshore during the warmer months, accompanying cold-water upwellings. From September through November lake trout move inshore to spawn, which usually occurs at night in less than 36 m (120 ft) of water (Scott and Crossman 1973) and usually on boulders, rubble or gravel. Preferred spawning temperatures range from 8.9-13.9 C. Eggs are from 5-6 mm in diameter and a large female may contain as many as 18,000 eggs. Incubation takes place during winter months with the period varying from 15-20 weeks depending upon temperature range (0.3-1.0 C). The young move offshore within about a month after hatching and yolk sac absorption.

Although spawning in Lake Michigan is known to have occurred in every year from 1969-1974 (unpublished data--U. S. Fish and Wildlife Service), successful natural recruitment from stocked populations has not been observed following extinction of the original Lake Michigan lake trout stock during the mid-1950's. The exact cause of this reproductive failure is not presently known; degradation of many traditional spawning grounds may have contributed to it. Sea lamprey predation and commercial fishery exploitation were among factors which led to collapse of lake trout populations during the 1950's (Smith 1968). However, through extensive management and stocking programs coordinated by the Great Lakes Fishery Commission and maintained through joint efforts of the Michigan Department of Natural Resources, conservation agencies of Wisconsin, Indiana and Illinois and the Federal government, approximately 2×10^6 lake trout yearlings are planted annually in Lake Michigan and lake trout are now relatively abundant. Yearlings (12-18 months old) are planted at an average length of 150 mm (6 in). They grow rapidly, reaching a weight of 1,810 g (4 lb) in about 3 yr and attain sexual maturity in 6 or 7 yr. The average size of fish caught by sports fishermen is under 4,540 g (10 lb), although the North American record is 28.6 kg (63 lb, 2 oz) for a lake trout caught in Lake Superior in 1952. The largest specimen ever captured was taken in a gillnet in 1961 from Lake Athabasca, Sask., and measured 1257 mm (49.5 in) and weighed 46.3 kg (102 lb). Fish caught during our 1973 studies ranged from 130-857 mm (16.5-5950 g). Average adult size ranged from 650-700 mm (25.5-27.5 in) and 3000-3500 g (6.5-7.3 lb).

Lake trout are both predaceous and opportunistic in their feeding habits, eating a wide variety of organisms, particularly those which are abundant and readily accessible (Scott and Crossman 1973). Organisms eaten include zooplankton, crustaceans, aquatic and terrestrial insects, fish eggs including their own, many species of fish and upon rare occasions small mammals--mice and shrews (Scott and Crossman 1973). Fish constitute the bulk of the adult lake trout diet. Historically, sculpin and chubs constituted a large portion of their diet. Van Oosten and Deason (1938) found that in southern Lake Michigan cottids represented 72% by volume of the stomach contents of lake trout, and in northern Lake Michigan coregonids constituted 51% of the stomach contents. Wright (1968), in Lake

Michigan studies, found 97.4% of the volume of food eaten to be fish, mostly sculpins, alewives and smelt. More recent work by Chiotti (1973) in Lake Michigan near Ludington, Mich., showed three species of fish, alewife, sculpin and smelt, made up 90.8% of lake trout diet, with alewife being the most important single food item in terms of volume and frequency of occurrence.

During 1973, 218 lake trout were captured in the vicinity of the Cook Plant, 118 in standard series nets, unadjusted catch, and 100 during supplementary netting operations. Gillnets caught 212, trawls caught six and beach seines none.

A seasonal peak in numbers of lake trout caught occurred during September, October and November (Table B6). This correlated well with known onshore spawning movements during fall months. From December through June, occurrence of lake trout in inshore waters of southeastern Lake Michigan is relatively infrequent. Examination of the data (Table B40) suggests several general patterns of lake trout movement. The most obvious was the higher level of nighttime activity, when 83% of the fish in standard series catches were caught. Observations from supplementary catches (Table B41) also showed heightened nocturnal activity. As the majority of lake trout were captured during the fall spawning months, inferred higher nighttime activity may be attributed in part to spawning behavior; spawning is known to take place after dark (Scott and Crossman 1973). It is

TABLE B40. Comparison of monthly day-night catches of lake trout in gillnets during 1973 from standard series nets set in Cook Plant study areas, southeastern Lake Michigan. Numbers caught were adjusted to catch per 12 hr.

Station	Time	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Cook Plant 6.1 m-Sta C	Day	---	0	0	0	0	0	0	1	3	6
	Night	0	0	0	0	0	0	0	33	27	19
Cook Plant 9.1 m-Sta D	Day	---	0	0	0	0	0	0	0	0	3
	Night	0	0	0	0	0	0	0	12	1	28
Warren Dunes 6.1 m-Sta G	Day	---	0	0	0	0	0	4	0	0	0
	Night	---	0	1	1	0	2	5	11	3	---
Warren Dunes 9.1 m-Sta H	Day	---	0	0	0	0	0	10	0	0	5
	Night	---	1	0	0	0	8	1	1	0	---

TABLE B41. Number of fish caught in gillnets and trawls fished at some supplementary stations. Catches were adjusted to number per 12 hr set for gillnets. Station A had a net set perpendicular to shore, 1.5 - 3 m of water; station E is 21.4 m; and trawling was done at station M near the St. Joseph River, 6.1 m of water.

Species[1]	STATION A									STATION E							STATION M					
	Apr 29	May 17	Jun 19	Jun 20	Jul 18	Aug 21	Sep 20	Oct 23	Dec 17	Apr 25	Jun 20	Jul 17	Aug 22	Sep 26	Oct 23	Nov 20	May 15	May 15	Aug 21	Aug 21	Oct 26	Oct 26
	Day	Night	Night	Day	Night	Night	Night	Night	Night	Day	Night	Day	Day	Night	Both	Day	Day	Day	Day	Day	Day	Day
SP	96	45	66	108	59	72	11	7								27	138	32	111	127	18	7
AL	280	209	1111	447	554	6	16	5					13	12	17		747	379			7	14
SM	21					3	2	3				1	5	4	23	5	14	9	22	108	3	41
YP		10	143	78	36	21				48	19		71	1	1	90		1	22	30		
TP	2	1			1			1			3		4	1	1	2			4	10	3	1
JD																	1		3	1		
WS		2	5	2	4	2	8	2								2						
LS		4	1		3		1								1	15						
LT	2	1				2	3	35		11	1		1	6	11							
CH						2		1														
RT		1					1	5	2													
CP	2	4	1	3	1		5	2														
CM		3					3		1													
BT	4	4					1	2														
NS																	1					
SS														1								
CC							1													1		
LG	2																					
NP	2					1	1	5														
GS							2	5														
XC											1		11	5	26						1	2
LW											1											
BF																						
BR									3													

[1] See Table B5 for definitions of species abbreviations.

unlikely that observed nocturnal activity could be attributed to feeding, as approximately 85% of the fish caught at this time had empty stomachs. Martin (1970) also noted a cessation of lake trout feeding activity during the spawning period, September through October.

Lake trout were captured more frequently at 6.1-m than at 9.1-m stations (Table B40). Supplementary netting (Table B41) supports the conclusion that longshore movements are more pronounced for lake trout than for most other non-salmonid species. All gillnets were set parallel to shore except those at station A, which were set perpendicular to shore. Catches from the perpendicular sets were higher for lake trout and other salmonids than catches from 6.1 and 9.1 m on the same day. Largest catch of lake trout occurred in station A nets during October (Table B41).

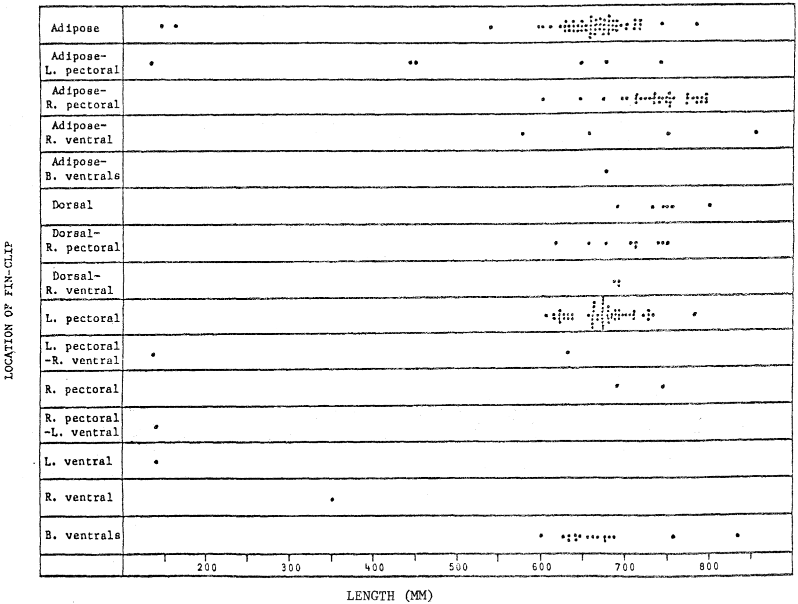
Examination of gonads (Table B42) showed an increase in ripeness of ovaries and testes beginning late in the summer and peaking during September with spent females first appearing in October. Observed gonad conditions and inferred September through November spawning period agreed well with the accepted classification of lake trout as fall spawners.

Length-frequencies of lake trout with various fin-clips were compiled (Table B43), and these data point out the preponderance of fish 550-800 mm

TABLE B42. Monthly gonad conditions of lake trout as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.					1			1			
Mod. dev.				1		6	13	6	8		
Well dev.	1		1					21	31	1	
Ripe-running									2	6	
Spent		2	1	1							
					Males						
Poorly dev.			3				1				
Mod. dev.						1	7	19	35		
Well dev.				1				9	15	4	
Ripe-running										4	
Spent		1						1	3	1	
					Unable to distinguish						

TABLE B43. Length-frequency distribution of fin-clipped lake trout caught during 1973 in Cook Plant study areas, southeastern Lake Michigan.



long that occur in the Cook Plant vicinity. No attempt was made to assign ages based on clips for this report, although it was noted that a considerable range of potentially overlapping lengths were present for a given clip. Problems in assigning ages are anticipated. Our catch data were compared with that for lake trout caught near Ludington (Chiotti 1973; Fig. B42), and good agreement was found between length ranges and modal sizes of fish captured. We caught more fish less than 300 mm, which we attribute to more extensive trawling during which time we caught six lake trout ranging from 130-158 mm, the only fish less than 300 mm. No adult lake trout were captured in trawls, probably because these larger fish were able to avoid the net.

Lake trout were caught most often in the temperature range 6-18 C (Fig. B43). Maximum catch occurred at 12-14 C, which agrees closely with preferred temperatures recorded in the literature (12 C, Ferguson 1958; 10 C, Daly et al. 1969). Scott and Crossman (1973) reported a spawning temperature preference range from 8.9-13.9 C. It may be that temperature preferences recorded to date are primarily a reflection of preferred spawning temperatures. To determine if there are differences between spawning and non-spawning temperature preferences, more temperature and catch data are needed for lake trout on a monthly basis, particularly during non-spawning months.

Unidentified Coregonids

As previously discussed in this section, difficulty was experienced in separating small lake herring (*Coregonus artedii*) and other rarer species of deep-water chubs from bloaters (*Coregonus hoyi*). However, since we believe probably all were bloaters, discussion below will be concerned with this species.

Historically the "chubs" comprised a seven-species complex, the smallest of which was *C. hoyi* (Smith 1964). A considerable commercial fishery operated throughout the period of first catch record (1879-1908). This fishery was quite exploitive, implementing many gear and mesh size changes. The largest two of the seven species became extinct in the 1950's and the next four largest species declined drastically between 1930 and 1961. Bloaters, the smallest of these species, increased in numbers over this same period due to reduced competition from larger chub species, which suffered from over-fishing and lamprey predation, and to reduced predation from lake trout, which also were a victim of the sea lamprey and perhaps over-fishing.

Since 1960-61 the bloater has been by far the dominant chub, and Wells (1966) has suggested that hybridization between bloaters and the remaining rare, larger species has occurred, confounding species identification problems.

Bloaters increased in average length between 1954-55 and 1960-61, at which time they were also becoming more abundant (Smith 1968). Indications are that this length increase began prior to 1954 and has continued on a yearly basis to the present. Bloaters reached maximum abundance during

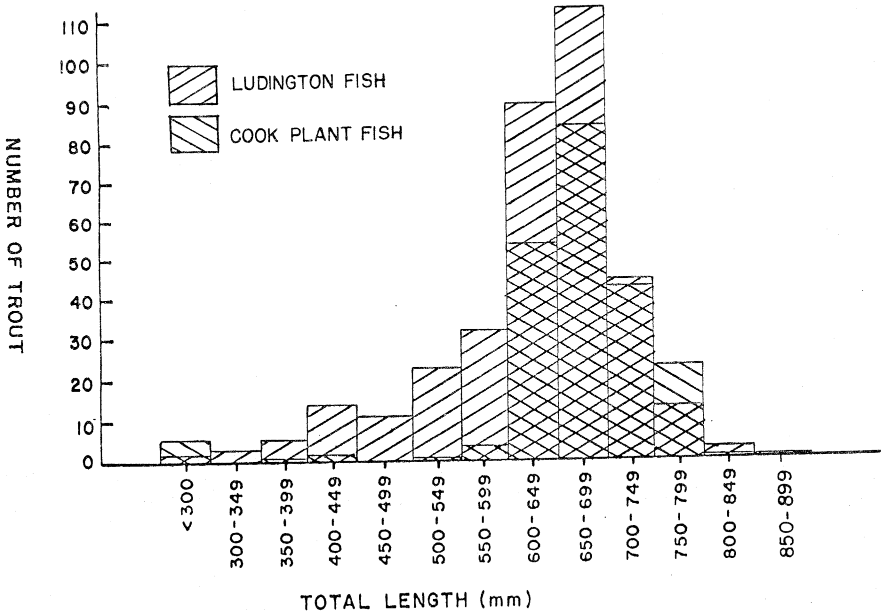


FIG. B42. Comparison of the length-frequency distributions of lake trout from Lake Michigan near Ludington (Chiotti 1973) and from Cook Plant study areas.

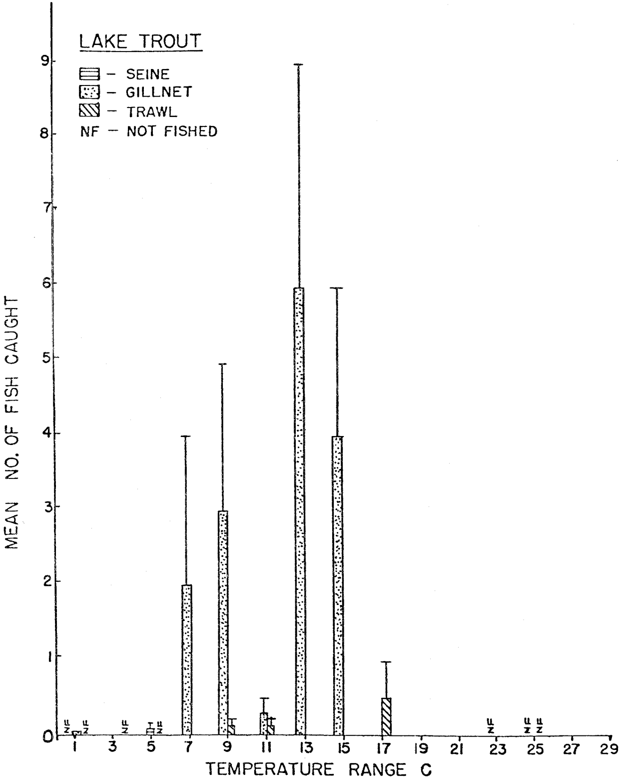


FIG. B43. Mean catch and standard error of lake trout at a given 2 C temperature interval in gillnets, seines and trawls during 1973 in southeastern Lake Michigan. Midpoint of temperature interval is given.

1960-61; populations have since been steadily declining (Stanford H. Smith, personal communication, University of Michigan, Ann Arbor). Reasons for this decline may include influx of alewives. Besides competing for food, alewives are present in great numbers when bloaters spawn January-March in depths of 73-100 m (Wells and McLain 1973), but whether alewives affect spawning success of bloaters is unknown.

Our catches of bloaters totaled 148 in standard series efforts, representing 0.08% of the total number for all species. They were the ninth most abundant fish captured and ranged in size from 68-314 mm (2.6-297 g). Bloaters were most abundant July through November, with July the month of greatest catch (60 fish); catches in August and June ranked second and third respectively. Overall, gillnets caught 84 fish, trawls 63 and one small individual (187 mm) was seined at station A (Cook). Ninety were caught at Warren Dunes stations, 58 at Cook Plant stations. There appeared to be a tendency for more to be caught during the night than the day. As 83% of all bloaters caught were from deeper water stations (9.1 m) and none occurred in gillnets set in shallow water at station A (Table B41), it would indicate that they seldom venture within the 6.1-m depth contour.

Wells (1968) concluded from seasonal trawling studies off Saugatuck, Mich., that bloaters are at midlevels in Lake Michigan until their third year of life. He found largest numbers during February, March and April in depths greater than 37 m (120 ft). We caught no fish during these months and none were caught in a gillnet set at 21.4 m (70 ft) in April, supporting the statement that this species is in deeper water in the vicinity of the Cook Plant during February through March. Bloaters have been found to start moving shoreward in May, and by July greatest numbers were at depths shallower than 31 m (100 ft) (Wells 1968). Our greatest catches were during July, when 60 were caught. Pronounced inshore movements of most fish are related to spawning activities; however, it appears that bloaters are there for other reasons, since they spawn at a later time and in deep water. Cursory examination of food eaten by bloaters in July revealed that they were eating *Eurycercus* sp. (benthic zooplankters), small *Pontoporeia affinis* (a benthic amphipod) and benthic snails. Most fish had been feeding. We believe that bloaters are associated with hypolimnion waters, and during upwellings the fish appear in our inshore nets. Large catches have also been obtained when inshore waters were cooled from upwellings (Wells 1968), which occurred during our trawling activities in June, July and August. An upwelling was also noted in September with no apparent effect on catch (2 fish); it appears most bloaters had retreated to deeper waters by then. A moderate catch in August at station E, 11 fish per 12-hr set, and large catches in trawls inshore (9.1 and 6.1 m) indicate a wide depth distribution at this time. In October a moderately large catch of bloaters was obtained trawling, and three were taken in 6.1 m of water off the mouth of the St. Joseph River. Fish should have been in deeper waters by then (Wells 1968). No bloaters were caught in November and December in the standard series nets or in a gillnet set at 21.4 m (70 ft); no trawling was done in November. It appears that movement to deeper water was complete by the end of October as catches at station E (21.4 m) peaked in October (Table B41). Wells (1968) found pronounced movement into deeper water in the fall, with largest concentration at 64 m (210 ft) in October and November. Jobes (1949) also suspected a movement toward shore in summer and return to deep water in fall.

Previous studies found little variation in length of fish in catches at different depths or in different seasons (Wells 1968). Sixty percent of our catches (Table B44), which were influenced considerably by greater numbers of large females caught in gillnets, were between 226 and 285 mm; Wells (1968) found 97% of his trawl-caught fish were between 178 and 251 mm. Even disregarding gillnetted fish, most of our trawl-caught larger specimens were in the range 230-260 mm, suggesting larger individuals in the population since Wells' data collected in 1964. It is also possible that larger individuals inhabit inshore waters. Another salient feature of the data (Table B44) is that twice as many females as males were caught with gillnets while the inverse was true for trawls. The trend is clear that trawling caught only the smaller females, most of the males, and almost all of the smaller immature individuals. Gillnets caught a major proportion of the large females and some of the larger males. Small fish 66-125 mm occurred in catches of June and October, with one 130-mm specimen caught in August. Fish this size are probably YOY (L. Wells, personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service).

Concern over the sex ratio being highly predominated by females was discussed by Brown (1970) and Smith (1968), who predicted a severe decline in stocks. More YOY and yearlings, however, were observed in experimental fishing hauls by Wells in 1970 with an accompanying increase in the proportion of males in the population. He suggested a possible recovery of bloater stocks could occur which our data appear to support as a fair number of males were present in each month--overall sex ratio was 59 males, 83 females.

Our data suggest that spawning occurs mainly in June, though some appear to be spawning through August (Table B45). Personal communication with Wells indicates that we may be in some error in judging ripe females, as eggs apparently become considerably more developed than we have seen. Wells (1966) reported that the spawning season in Lake Michigan is January-March. Scott and Crossman (1973) reported spawning occurred generally in February through March, but many observers remarked that some spawning must be occurring at all times as ripe and spent fish were taken throughout the year. Bloaters may spawn over all bottom types in depths of water from 36.5-91.4 m (120-300 ft) (Scott and Crossman 1973). Our data cover only May through October, but a definite trend toward spent and then poorly developed gonads is apparent from June through August. Wells (1968) found a temperature preference of 5-10 C for trawl-caught bloaters from Lake Michigan. In our study, bloaters were caught at temperatures from 6-20 C with highest catch at 12-14 C (Table B46). The one seined bloater was caught at 10-12 C. Reasons for the warmer temperatures at which bloaters were caught when compared with Wells is undoubtedly related to the fact that we sampled only the inshore tip of the main bloater concentration, thus water temperatures tended to be somewhat warmer than those obtained by Wells in colder water.

Longnose Sucker

In northern North America, longnose suckers occur almost everywhere in clear, cold waters in moderately large numbers, while in the south numbers are fewer and more sporadic (Scott and Crossman 1973). They are the only North American suckers which occur in Asia (extreme northeast), and are

TABLE B44. A length-frequency table for unidentified coregonids caught during 1973. Values are the unadjusted, actual numbers of fish captured in all sets. Sex and the type of gear in which fish were caught is given. S = seines, T = trawls, G = gillnets, M = male, F = female, 0 = other, which includes immature and undetermined sex.

Mid-point of length interval (mm)	May			June			July			August			September			October			Total
	M	F	0	M	F	0	M	F	0	M	F	0	M	F	0	M	F	0	
60																			
70						1T												3T	4
80						1T												8T	9
90						3T												10T	13
100						1T,1G												1T	3
110																			
120						2T													2
130										1T									1
140																			
150																			
160										1T									1
170						1T													1
180				1T		1T				1T									3
190			1S		1G		2T										1G		5
200							1T			2T						1G			4
210							2T,1G				1G								4
220					1T					1T,1G	2G								5
230		1G			1T,1G	1T	1T,2G	1G		2T,2G	1T					1G			14
240				1T	1G	1G	1T,2G	1T,1G			3T,2G					1G			14
250				1G	1T,3G		2G	1T,1G		3T,2G	1T,1G		1G	1G		3G	4G		25
260					1G		3G	2G,1T		1T,1G	5G		2G	1G		5G	5G		27
270					1T		2G	4G		1G						2G	7G		17
280					2G			4G		1G	1T,1G						5G		14
290								3G					1G				1G		5
300								1G									1G		2
310								3G									2G		5
sums:	0	1	1	3	13	13	19	23	0	20	18	0	4	2	0	13	26	22	178

TABLE B45. Monthly gonad conditions of bloaters (unidentified coregonids) as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.									2		
Mod. dev.				1	2	2	12	2	24		
Well dev.					12	20	6				
Ripe-running											
Spent						2					
					Males						
Poorly dev.					1	1	4	1	8		
Mod. dev.							11		5		
Well dev.					2	11	3				
Ripe-running											
Spent						6	2	3			
					Unable to distinguish						
					2				3		

found only in the northern third of the United States (Scott and Crossman 1973). While found in the deeper waters of the Great Lakes, they are not as common in Lake Michigan as white suckers.

In Lake Michigan, longnose suckers constituted a minor portion of the commercial sucker catch (see "White Sucker," this section, for commercial catch statistics). They were captured mostly during spring and summer and were the tenth most abundant species collected in our standard series nets during 1973 (Table B6).

While 86 longnose suckers were caught in standard series nets, a total of 158 were caught by all fishing during 1973 (Table B47). The majority of these were 275-400 mm in total length, but larger adults 400-550 mm were caught in appreciable numbers. In the colder months February, March, September, October and November, mostly large adults were caught, while smaller suckers were caught only in late spring and summer. Total numbers caught per month were not as consistent as catches of white suckers.

As with white suckers, numbers of longnose suckers caught in April were low, possibly related to spawning behavior in both cases. Gonad development data (Table B48) indicated that spawning probably occurred in late March, April and May. Harris (1962) found longnose suckers spawned during May and June in tributaries to Great Slave Lake at water temperatures of 10-15 C.

TABLE B46. Temperature-catch relationships of unidentified coregonids inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—					$.1\pm.08$		—						
G				2 ± 2	$.6\pm.5$	$.3\pm.3$	2 ± 1	$.2\pm.2$		3 ± 3			—	—
T	—	—	—		$.2\pm.2$		$2\pm.6$	$1\pm.3$	$2\pm.5$	$.5\pm.2$			—	—

Longnose suckers spawned in tributaries of Yellowstone Lake during June and July (Brown and Graham 1954). Bailey (1969) reported Lake Superior longnose suckers spawned in the Brule River from April to May when water temperatures were 11-14 C; average for 7 yr of records was 13 C. From other studies, Scott and Crossman (1973) concluded that spawning occurs in streams, or in shallow areas of lakes where streams are not available, during April and May when water temperature exceeded 5 C. Inshore water temperatures in southeastern Lake Michigan (Seibel and Ayers 1974) began consistently exceeding 5 C in late March and April. In April, fish were scarce in the sampling area so they were probably spawning in tributaries to the lake.

By comparing lengths of fish we caught with average lengths for age groups compiled by Carlander (1969), some general conclusions will be made on ages of longnose suckers in southeastern Lake Michigan. The two smallest fish caught were probably 1 and 2 yr old (Table B47), those from 225-400 mm probably 3-6 yr old, those above 500 mm probably 8 to possibly 13 yr old. In general, it appears that growth of longnose suckers in southeastern Lake Michigan is similar to or possibly somewhat better than growth of suckers from other habitats.

Most longnose suckers caught during 1973 were captured by gillnets (Table B49) during April through July, with July the month of maximum catch in standard series fishing (Table B6). Longnose suckers are vulnerable to gillnetting, as are white suckers. Apparently these larger fish effectively avoid trawls and seines. Paucity of small fish in our catch is an enigma. It may be that juveniles do not utilize inshore waters off Warren Dunes and the Cook Plant, or they may spend parts of their early lives in rivers, streams or deeper areas of the lake.

Almost three times as many longnose suckers were caught during the night (63) as during the day (23) in standard series fishing (Tables B7,8). About equal numbers of adults were caught at the 6.1-m and the 9.1-m station in each area. It appeared that fish came into shallower waters at night but not during the day. At deeper stations, longnose suckers were present

TABLE B47. Monthly length-frequency distributions of longnose suckers caught during 1973 in southeastern Lake Michigan at the Cook Plant study site. Catches from all gear are pooled. No fish were caught in January and December.

Length interval (mm)	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Totals
0–24											
25–49											
50–74						1					1
75–99											
100–124											
125–149											
150–174				1							1
175–199											
200–224											
225–249				1							1
250–274				1							1
275–299				14	1						15
300–324			4	13		1					18
325–349			5	13		11	1				30
350–374				2		17					19
375–399				2	3	4					9
400–424					3						3
425–449		6			1	8				2	17
450–474	1	2		1	1	1				1	7
475–499	2	3			3	1		2	2	3	16
500–524		6			1				1	5	13
525–549		1			1					4	6
550–574										1	1
Totals	3	18	9	48	14	44	1	2	3	16	158

TABLE B48. Monthly gonad conditions of longnose suckers as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.				1			1				
Mod. dev.		3							2	5	
Well dev.	1	8								3	
Ripe-running											
Spent		2		2	8	21					
					Males						
Poorly dev.				1		1					
Mod. dev.		2	1	3		1		1		7	
Well dev.		3	2	5				1	1		
Ripe-running											
Spent				7	5	4					
					Unable to distinguish						
				11	1	3					

during day and night. Apparently they prefer deeper waters than do white suckers, as more white suckers were caught at 6.1-m than at 9.1-m stations. Many longnose suckers were caught at station E (Table B49), indicating that their depth range is out to at least 21.4 m. Larger longnose suckers are more abundant in the Warren Dunes area than in the Cook Plant area, as was found for white suckers; the factors causing this increase are unknown.

Temperature-catch data (Table B50) indicated that most adult fish were caught when water temperatures were 10-14 C. It is clear this species is a cold-water fish, both from its northern distribution and its presence in only the colder waters of Lake Michigan.

Rainbow Trout

Rainbow trout, thought to be sea-run stock, were first introduced into Lake Michigan in 1880, with many subsequent plantings (Wells and McLain 1973). Stocking has greatly increased since 1960, with the catch from these plants estimated as 275,000 in state of Michigan waters in 1970. Both anadromous steelhead and rainbow trout landlocked or freshwater are present in Lake Michigan. We made no distinction between them in our catches. Adult steelhead spawn in streams and tributaries (Hart 1973), usually in winter; rainbow trout are basically spring spawners. There is little evidence

TABLE B49. Length-frequency distributions of longnose suckers caught during 1973 with gillnets, seines and trawls at eight stations near the Cook Plant, southeastern Lake Michigan.

Length interval (mm)		Fishing gear			Station								
		Gillnet	Trawl	Seine	A[1]		B	F	C	D	G	H	E
0-24													
25-49													
50-74				1		1							
75-99													
100-124													
125-149													
150-174				1				1					
175-199													
200-224													
225-249		1			1								
250-274		1										1	
275-299		15			1					1		1	12
300-324		17		1	2			1	2	5		4	4
325-349		28	2		1				7	7	3	9	3
350-374		19			1				2	1	10	5	
375-399		8	1						4		4	1	
400-424		2	1						1	1		1	
425-449		17			3						5	4	5
450-474		7			2				1		2	1	1
475-499		15	1		3				2	1	3	2	5
500-524		13			5						1		7
525-549		6								2			4
550-574		1											1
Total	Day	22	2	1				1		4		20	
	Night	128	3	2	19	1		1	19	14	28	9	42

[1] At station A, both seining and gillnetting were performed, first column is gillnetted fish, second is seined fish.

TABLE B50. Temperature-catch relationships of longnose suckers inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	--					$.1\pm.1$		--			$.04\pm.04$			
G	$.5\pm.3$	$.2\pm.2$	$.8\pm.5$	1 ± 1	$1\pm.5$	2 ± 1	2 ± 2	$.9\pm.9$	1 ± 1	$.4\pm.3$			--	--
T	--	--	--						$.5\pm.3$	$.4\pm.1$	$.5\pm.3$		--	--

that rainbow trout can successfully spawn on beaches of lakes that do not have rivers running into them. Great Lakes populations enter some spawning streams from late October to early May and spawn from late December to late April (Dodge and MacCrimmon 1970). Our gonad development data (Table B51) suggest that most rainbow trout in the vicinity of the Cook Plant were ready to spawn in October, as five individuals had ripe-running sex products. However, two large fish of opposite sex seined during February were also ripe-running, indicating a late fall through winter spawning season for rainbow trout we caught.

It appears that we may indeed be getting a good sample of fish from all over the lake. One rainbow we captured in a gillnet in December was tagged by Argonne Laboratory personnel in October at the Point Beach Power Plant in Wisconsin. Scott and Crossman (1973) reported a rainbow captured in Lake Ontario in 1958 which had been released in Great Lakes rivers in Michigan; in a period of 8 months it had traveled about 600 miles and grew 254 mm in length. However, they stated that lake resident trout do not normally utilize a large territory.

In standard series catches (Table B6), rainbows were most often caught from April through August with May the month of maximum catch (30). A total of 86 (0.04% of total) was captured, three in gillnets, the remainder in seines. Thirty-six were caught during the day, 50 at night. Of all specimens captured in 1973, the smallest was 113 mm (16.1 g), the largest 715 mm (4725 g)--caught in a gillnet at station A in October.

Seasonal distribution of catch indicates the utilization of different areas by adults and juveniles. One rainbow trout (358 mm) was seined in March; in April all rainbows except one large gillnetted trout were small (140-193 mm) and caught by seines. In May, June, July, August and September, a similar pattern was evident; most fish were small and were caught with seines in inshore waters. In October a number of rainbows were seined as in previous months, but in addition several rainbows were caught in gillnets set perpendicular to shore at station A (Table B41). None were taken in

TABLE B51. Monthly gonad conditions of rainbow trout as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.		1								1	
Mod. dev.									8		
Well dev.		4							31		
Ripe-running	1								2		
Spent		1		1							
					Males						
Poorly dev.									35		
Mod. dev.								1	15	1	1
Well dev.	1	4		1							
Ripe-running	1		1						3		1
Spent											
					Unable to distinguish						
					1	1					

standard series nets set parallel to shore at 6.1 and 9.1 m. It is evident that large rainbows, like brown trout and lake trout, travel the inshore waters close to shore with longshore currents during certain times of the year, usually spring and fall. All five rainbows caught in November were relatively small individuals 113-304 mm, again caught while seining. Small rainbows probably inhabit the beach-zone waters during the months of April through at least November. Rainbow trout were also one of the few species which appeared in the area of the Cook Plant during winter (Table B41, December data).

Upper lethal temperature of Kamloops trout fingerlings (*S. gairderni*) was found to be 24 C when acclimated to 11 C (Scott and Crossman 1973). Final preferred temperature was 13 C (Garside and Tait 1958). Rainbow trout were reported most successful in habitats with temperatures of 21 C or slightly lower. Consulting our gillnet data (Table B52), which are selective for large rainbows, we found most trout were caught at 4-12 C, which is in fair agreement with their final preferred temperature. Seining data showed small fish were most often caught at 4-26 C. Peaks were noted at 10-14 C and 24-26 C, again indicating that these smaller fish can tolerate quite a range of temperatures. The most persistent trend in this data is presence of small rainbows in beach-zone waters, seemingly oblivious of water temperature.

TABLE B52. Temperature-catch relationships of rainbow trout inferred from mean catch over 2 C temperature intervals in seines (S), gill-nets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	--		$.5 \pm .5$	$.7 \pm .4$	$.8 \pm .2$	2 ± 1	$1 \pm .6$	--	$.3 \pm .2$	$.2 \pm .2$	$.8 \pm .4$	$.4 \pm .2$	1 ± 1	
G			$.1 \pm .1$		$.6 \pm .5$	$.2 \pm .2$							--	--
T	--	--	--										--	--

Sculpins

The slimy sculpin is a small fish with an average adult length of 70 mm (3 in). Its range extends from northern North America into extreme north-eastern Siberia, occurring from Virginia, Labrador and Ungava on the east, and westward through most of northern North America to Alaska and St. Lawrence Island in the Bering Sea (Scott and Crossman 1973). Wells (1968) notes that slimy sculpins beyond earlier growth stages ordinarily are considered strict bottom dwellers, though some ascent off the bottom does occur. Little is known of the biology of this species, and no known food habit studies have been done in southeastern Lake Michigan (Rottiers 1965). The spawning season (Richardson 1836; Scott and Crossman 1973) occurs in May, and spawning temperatures are reported from 5 C in Cayuga Lake to 10 C for a spring stream (Scott and Crossman 1973). Prior to spawning, the male constructs a nest under stones, tree roots or ledges. The adhesive eggs of one or often more females are deposited on the ceiling of the nest. The male guards the eggs during the incubation period and even after hatching. Slimy sculpins prefer rocky or gravelly substrates in the deeper waters of lakes and cool streams where they can seek shelter and hide during the day (Hubbs and Lagler 1964). Occurrence of sculpins in riprap areas around the intake and discharge structures has been noted by project SCUBA divers, and on 21-22 May 1974 divers found fish eggs attached to the underside of riprap in the area of the south intake structure (9.1 m) and the north discharge structure (6.1 m). Water temperature was 11.1 C. Numbers of eggs on each of the two pieces of riprap were estimated to range between 300-600, which would indicate that the egg masses were each laid by a single female. Eggs were transported to our field laboratory, and hatched within hours. Larvae were identified as sculpin (*C. cognatus* or possibly *C. bairdi*).

Inability of divers to locate other egg masses in the area on subsequent dives and the rapid hatch of the two samples obtained indicated that the date of collection of the eggs approximated the end of the 1974 hatching period for sculpin in the area. Rottiers (1965) found spawning of slimy sculpins to peak in this area in early May. Scott and Crossman (1973) cited an incubation

period of 4 weeks at 8 C. We captured 56% of our sculpins during April in 1973. Based on the above observations, the 1974 spawning period for sculpin in this area can be estimated to have occurred between early April and early May, with a peak hatch most likely taking place between late April and early May. At hatching, the eggs collected ranged between 2.3-2.8 mm in diameter, and the newly hatched larvae measured 6-7 mm T.L. R. J. Benda (personal communication, Aquinas College, Grand Rapids, Mich.) found sculpin larvae in his entrainment samples at the Palisades Nuclear Plant north of the Cook Plant.

Survey data from Lake Michigan collected by the U. S. Fish and Wildlife Service in the late 50's and early 60's reported a depth distribution for slimy sculpins of 5.5-129.8 m (18-426 ft) Wells 1968). The depth range at which they most commonly occurred was 36.6-73.2 m (120-240 ft). They are an important item in the diet of lake trout (L. Wells, personal communication, Great Lakes Fishery Lab., U. S. Fish and Wildlife Service).

It should be noted that due to problems in distinguishing mottled and slimy scuplins, they have been combined in this section and will be collectively referred to as slimy sculpins. It is believed that most are slimy sculpins (see "Methods," this section). Slimy sculpins accounted for 0.04% (80 individuals) of the total number for all species in standard series catches in 1973. Of the total caught, 44 were collected in April and 14 in May. None were caught during July, indicating this fish's general movement from the area during this period of seasonal warm water. However our SCUBA divers did note some, perhaps a localized population, around the intake and discharge structures.

Most sculpins were captured at night (Tables B7, 8). Of the three fishing methods employed, the majority of fish were taken by trawls. Beach seines were the next most productive, followed by gillnets (one was caught at 9.1 m--Cook). The 19 sculpins caught during the day were taken in trawls; none were caught in day beach seines. During night trawls, 53 were taken. Night catches at seining stations A and B, Cook Plant, were somewhat larger than those at station F. Day catches of sculpin at Cook Plant stations, all gear, were larger than comparable stations at Warren Dunes. Larger catches recorded at night may be related to nocturnal behavior of this species (Hubbs and Lagler 1964). Larger catches in trawls were attributed to selectivity of the gear for bottom dwelling fish such as the sculpin. At Cook, similar trawl catches were made at 6.1 and 9.1-m stations; at Warren Dunes a greater catch was made at the 9.1-m than the 6.1-m station. Fish captured ranged from 20-135 mm, with most fish in the 46-95 mm range (Table B53). Rottiers (1965), in his age and growth study of southeastern Lake Michigan sculpins, found the following lengths associated with each age group: I, 30-40 mm; II, 35-59 mm; III, mostly 55-84 mm; IV, 70-94 mm; V, 85-104 mm; VI, 90-109 mm; and VII, 105-109 mm. Most of his fish in the III-IV age groups were taken from the deeper areas of Lake Michigan. According to his groupings only 24 of 261 fish we captured (Table B53) were not in age groups III to V. Sex ratios were about equal for most months, with the overall composition 90 males : 95 females. Males tended to be larger than females.

The large catch in April is thought to be due to sculpins coming inshore to spawn. Examination of gonads revealed that those taken at this time were gravid (Table B54). In trawling studies off Saugatuck, Wells (1968) found

TABLE B53. A length-frequency table for sculpins caught during 1973. Values are the unadjusted, actual numbers of fish captured in all sets. Sex and type of gear the fish were caught in is given. S = seine, T = trawl, G = gillnet, E = impinged, M = male, F = female, O = other, which includes immature and undetermined sex.

Month	Sex	Mid-point of length interval (mm)												
		20	30	40	50	60	70	80	90	100	110	120	130	sums
Feb	M							9E	2E	1E				12
	F					3E	3E	4E	1E				1E	12
	O					1E		1E	3E	1E				6
Mar	M							2E,1G	1E	1E				5
	F						1E							1
	O													0
Apr	M						5T,6E,1S	9E,7T	11E,4T	3E	1E			48
	F				1S,1F	2S,5E,11T	2S,15E,6T	7E,4T,2S	1G,3E					59
	O			2T	1E,1T,1S	7E,1T	6E,1T	6E						26
May	M					1T		3T						4
	F				1S	1T								2
	O		1T	4T	5T		1T							11
Jun	M			1T	2T	1T	4T		2T					10
	F						1T							1
	O			1T	7T	2T	2T	1T	1T		1T			15
Jul	M							1T						1
	F						1T							1
	O		2T			1T				1T				4
Sep	M					1T	1T							2
	F			1T		1T								2
	O	1T	3T							1G				5
Oct	M					1T	1T			1T				3
	F			1T					1T,1E	1T				4
	O		2T	1T				1E						4
Nov	M									1E				1
	F						1E							1
	O		1S				1E							2
Dec	M					1E	1E		2E	1E				5
	F				2E		1E	6E	1E	1E				11
	O				1E	1E				1E				3
Sums		1	9	11	23	40	62	64	34	14	2	0	1	261

TABLE B54. Monthly gonad conditions of sculpins as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Females										
Poorly dev.								1	3		2
Mod. dev.	1			1				1			2
Well dev.	11		47	1							7
Ripe-running		1	12								
Spent			3		2		1		1	1	
	Males										
Poorly dev.			1		1				3	1	
Mod. dev.	12	1	10	1			1	1			2
Well dev.		4	36	1	2						3
Ripe-running											
Spent			1	2	6			1			
	Unable to distinguish										
				1	10						

that slimy sculpins were distributed over a wide depth range in winter, moved inshore, then abandoned shallow areas in spring as soon as warming was significant; greatest numbers at 6 m (depth of shallowest samples) were in mid-April. They continued a gradual movement away from shore through summer and fall. Rottiers (1965) stated spawning probably occurred in southeastern Lake Michigan from before 5 May 1964 when 66% of his specimens were spent, until 23 May when almost all were found to be spent. Peak spawning was between 31 and 82 m early in the season and somewhat deeper later.

Sculpins were one of the more abundant species collected from traveling screens (impinged) during 1973. From these limited data (see Section D) and observation made by project divers, the presence of a local population of sculpins near the intakes is indicated.

Sculpins have been observed by SCUBA divers on numerous occasions in the vicinity of the Cook Plant. They and johnny darters are the species most consistently observed by divers in the riprap area. Sculpins were not seen in areas outside the riprap. It is quite likely that riprap may afford demersal fish such as sculpin sufficient protection to allow development of an inshore population in areas normally too harsh for continual habitation. Contrasting day versus night impingement catches and diving observations appear to verify the nocturnal activity of this species.

Rottiers (1965) states that the majority of slimy sculpins in Lake Michigan appear to prefer cold water, 6 C or less, except for short periods during fall overturn. Wells (1968) found the temperature preference of trawl-caught sculpins to be 4-5 C. Sculpins were caught in water temperatures ranging from 6-22 C (Table B55) with greatest catch at 6-8 C.

TABLE B55. Temperature-catch relationships of slimy sculpins inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—		.5±.5		.4±.2			—						
G			.1±.1										--	--
T	--	--	—	3±.5	.8±.2	.4±.2	.7±.3	.2±.1			.4±.3	--	--	--

A high incidence of spiny-headed worms (*Acanthocephala*) was observed in the lower intestinal tract of sculpins, up to seven in some of the larger specimens.

Brown Trout

Brown trout were stocked in Lake Michigan in 1883, and several hundred-thousand browns have been stocked in Lake Michigan since the mid-1960's (Wells and McLain 1973). These fish have provided a very successful sport fishery and, judging from the large size of some we caught, they are growing very well in Lake Michigan. In 1971, fishermen in the seven counties around the Cook Plant (District 12, Tody 1973) caught 42,480 brown trout, although many of these may have been taken from inland streams. Our data (Table B56) suggest fall spawning, but more adults are needed to judge adequately. Water temperature for spawning is listed as 6.7-8.9 C (Scott and Crossman 1973). They also noted that some brown trout spawned on rocky reefs along shore in Lake Superior.

During 1973, 76 brown trout, 0.04% of the total, were captured in standard series fishing (Table B6). Peak numbers were taken in June (33) and July (18). Twenty were caught during the day, 56 at night. Sixty-eight were caught while seining, seven by gillnet and one by trawl. There appeared to be little difference between numbers caught at Cook Plant and Warren Dunes. Range in size (standard and supplementary fishing) was 106 mm, 15 g, seined at station A in October, to 682 mm, a 4070-g male caught at night in a gillnet at station A. Browns from all fishing efforts in March and April were large, 267-543 mm; most were captured with gillnets from deeper water. In May, large

TABLE B56. Monthly gonad conditions of brown trout as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.				1			1			2	
Mod. dev.		3		1							
Well dev.								1		1	
Ripe-running											
Spent		8	1	2							
					Males						
Poorly dev.				1		4				2	
Mod. dev.					1						
Well dev.											
Ripe-running											
Spent		2									
					Unable to distinguish						
				2			1			4	

fish were again taken by gillnet, but a number of smaller trout 106-202 mm were captured in beach-zone waters with seines. In June and July, months of largest catches of brown trout, all were small and were caught by seines in beach-zone waters, indicating that smaller fish reside in these waters during the spring and summer months, and that larger browns probably move from warmer inshore waters to cooler, deeper waters of the lake during late spring and summer. In August and September, small fish were caught in seines and three larger fish in gillnets. The same pattern was seen for fish caught in October, indicating the movement of large brown trout back into the now cooler inshore waters.

Temperature optimum for brown trout was reported to be 18.3-23.9 C (Scott and Crossman 1973). Final temperature preference for age class II brown trout was reported as 12.4-17.6 C (Ferguson 1958). Our gillnet data (Table B57), which involve mostly larger specimens, suggest 6-16 C as temperatures most commonly frequented. Smaller fish were caught almost exclusively by seine, in water temperatures from 4-26 C, with indications that these fish preferred a higher temperature range than older adults.

Emerald Shiner

The emerald shiner, a minnow native to Lake Michigan, has undergone dramatic changes in its populations in recent years with the increase of alewife in the lake. In earlier years it was the most abundant inshore forage fish

TABLE B57. Temperature-catch relationships of brown trout inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—		.5±.5		.06±.06	.2±.1	.2±.2	—	.8±.8	.2±.2		.9±.4	.6±.3	
C				.4±.2		.3±.3	.2±.2	.1±.2					—	—
T	—	—	—							.1±.1			—	—

but has almost disappeared since the 1960's (Wells and McLain 1973). It is postulated that emerald shiners, which feed mainly on zooplankton, were decimated because of their inability to compete with alewife young and adults which inhabit the same areas of the lake inshore during spring and midsummer. Commercial utilization of emeral shiners has been as bait, both fresh and pickled.

In our standard series sampling we caught 49 individuals, 0.03% of the total, all in seines (Table B7 and B8). Monthly catches of emerald shiners remained low but constant for most of 1973. The only peak in monthly catches was in August and September. Emerald shiners were caught almost exclusively at station B south of Cook. Stations A and F both accounted for only five individauls, while station B accounted for 39. This is thought to be related to the sheltered nature of station B afforded by the sand replenishment program initiated to curtail erosion south of the former safe harbor.

Length range for the emerald shiner was 43-96 mm, average length 64 ± 1.8 mm (S. E.). Examination on a monthly basis showed a relatively constant length regime from month to month. Gonad data are scanty because of difficulties in sexing these fish.

Emerald shiners were caught in water 4-28 C with greatest catches in temperatures of 26-28 and 18-20 C (Table B58), indicating that they are eurythermal with a definite preference for higher temperatures. It might be hypothesized from regular occurrence in seine catches as well as broad temperature tolerance that shiners occupy the beach-zone waters during most of the year. None have been collected from traveling screen catches to date, also indicating a beach-zone distribution.

Longnose Dace

Spawning habits of longnose dace have not been studied to any extent, but it is thought that spawning occurs in May, June or early July in riffles and on gravelly bottoms (Scott and Crossman 1973.

TABLE B58. Temperature-catch relationships of emerald shiners inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—		.5±.5	.1±.1	.1±.08	.5±.2	.2±.2	—		1±1	.5±.3	.6±.3	.4±.4	2±1
G													—	—
T	—	—	—										—	—

Longnose dace accounted for 0.02%, 41 fish, of the total number captured in standard series fishing (Table B6). They appeared only in seine hauls, with 36 caught at station B south of Cook. Seining at station A and F accounted for three and two respectively. The vast majority of station B catches were taken at night. This station was just beyond the area where large mounds of sand were located for sand replenishment because of the safe harbor and as a result was broad and shallow. As found with emerals shiners, this feature is thought to contribute to the larger catches.

Occurrence of longnose dace was relatively constant for all months except September when 22 were collected, all but two at night. Length range was 30-80 mm, average length 49±1.6 mm (S. E.). Examination of monthly length ranges showed an increase in size of individuals for June through July, however the number caught was small.

Longnose dace were caught in water temperatures from 2-26 C, with greatest catch at 22-24 C (Table B59).

TABLE B59. Temperature preference of longnose dace inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—	.5±.5	.5±.5		.1±.08	.4±.2		—			.5±.2	1±.7	.4±.3	
G													—	—
T	—	—	—										—	—

Northern Pike

Northern pike were captured regularly although in low numbers during our sampling. They are a warm-water species and probably enter Lake Michigan as YOY or adults from rivers and lakes and from areas like Green Bay, Wis., where sizable populations exist. Annual production of northern pike averaged 2.9 x 10^4 kg (46,000 lb) from 1899-1970 (Wells and McLain 1973). They are sight feeders and most active during daytime. They spawn in the spring in April to early May when water temperatures are 4.4-11.1 C, almost invariably in areas of flooded vegetation or in marshes or shallow weedy bays (Scott and Crossman 1973).

In standard series efforts, 38 were captured, 15 in October (Table B6). They were taken in 5 of the 11 months fished. More northerns were caught during the day (22) than at night (16), 31 from gillnets, five small fish (age class I) in seines, and two in trawls. Range in size of fish captured was from 98-815 mm (5.2-4150 g). Most fish were 300-500 mm long (about 2-4 yr old--Scott and Crossman 1973). No adult fish were caught during spawning, so ability to corroborate known spawning times is limited. Data (Table B60) suggest, however, that spawning occurs sometime after March; northern pike gonads were poorly developed from August through December.

These fish were most frequently caught at temperatures of 8-24 C (Table B61).

TABLE B60. Monthly gonad conditions of northern pike as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immatures and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.							1	2	8	2	1
Mod. dev.									1		
Well dev.		2									
Ripe-running											
Spent											
					Males						
Poorly dev.								6	11		
Mod. dev.								3	1	1	
Well dev.											
Ripe-running											
Spent			1								
					Unable to distinguish						
								2			

TABLE B61. Temperature-catch relationships of northern pike inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—					$.1 \pm .08$		—	$.2 \pm .2$			$.1 \pm .06$		
G					$.5 \pm .2$	$.8 \pm .8$	$1 \pm .6$	$.3 \pm .2$				1 ± 1	—	—
T	—	—	—		$.1 \pm .1$		$.2 \pm .1$						—	—

Coho Salmon

Introduction of coho salmon into Lake Michigan began in 1966 with release of 660,000 yearlings (Wells and McLain 1973). A total of 10.3 million have been stocked through 1970. A considerable sport fishery is now enjoying the results of those efforts as anglers in Michigan waters caught an estimated 500,000 coho in 1970. Catch rates tended to be greatest in statistical districts MM-5 (Grand Traverse Bay area) through MM-8, which includes the Cook Plant vicinity (Tody 1973). Spring salmon fishing is concentrated almost exclusively in the MM-8 district. Adult coho salmon weighed an average of 4,313 g (9.5 lbs) in the spawning runs of 1967-69.

Average weight of Lake Michigan coho has been reported as 500-900 g for 1-yr olds (age group II) and 4000 g for 2-yr olds (age group III) during 1966-70 (Parsons 1973). Coho (smolt-age group I) were planted in the St. Joseph River in 1969 and 1970, 100,000 each time (Parsons 1973). Coho were reported by Engel and Magnuson (1971) to be inshore in spring and fall and in the thermocline during late summer in a small lake in Wisconsin. Anadromous coho spawn in the fall in rivers and streams, and much natural reproduction has occurred in Lake Michigan (Parsons 1973; Tody 1973). Our gonad data indirectly substantiate fall spawning, as most fish from March through June had poorly developed gonads (Table B62). It is assumed salmon became gravid in the fall. Eggs are laid deep in gravel from October to November, and fry emerge from beds around April, remaining in streams for varying lengths of time (Hart 1973). Wells and McLain (1973) stated that introduction of the salmonids has probably had little effect on native fish stocks, but their main effect may be through their probable reduction of alewife populations.

We caught 32 coho salmon during standard series fishing, 0.02% of the total number of fish taken. Since the Cook Plant is not close (within 18 km) to any rivers or major streams (there are intermittent streams, one about 3 km north, an outlet from Grand Mere Lake, and one about 1.6 km south near Weco Beach) coho salmon do not concentrate to any extent in the area. This is probably the reason for our low catch of these salmonids. Coho do travel

TABLE B62. Monthly gonad conditions of coho salmon as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.		1		1							1
Mod. dev.		5	3	4							
Well dev.								1			
Ripe-running											
Spent				9							
						Males					
Poorly dev.		5		8	1						
Mod. dev.			1					1			
Well dev.								4			
Ripe-running											
Spent				1							
					Unable to distinguish						
				1					2		

occasionally with the longshore currents during certain seasons. They are quite abundant in and around the mouth of the St. Joseph River, about 18 km north of the Cook Plant.

Most coho in standard series catches were taken in May and June, none during February, July, August, November and December. More (23) were caught during the night than during the day (9). More were caught with gillnets than with seines, none were taken with trawls (Table B7, 8). Coho captured, total fishing efforts, ranged from 73-845 mm (3.7-4610 g). During March, April and May most fish caught were large, from 350-550 mm long. In June all coho caught except one 483-mm specimen caught with a gillnet, were taken with seines at all three seining stations. These six fish ranged from 73-95 mm, indicating small coho are probably inhabiting beach-zone waters during June. A slight possibility exists that these coho may have been naturally produced since Parsons (1973) states that coho are planted at about 101-152 mm during March through May. No small coho were caught in July through December. In September, October and December, coho taken were longer, ranging from 500-845 mm. The only gillnet set in December was a supplementary set at station A. Coho salmon was one of three species captured (burbot and rainbow trout were the others), indicating coho may be in the vicinity of the Cook Plant inshore waters at least during early winter.

Temperature preference of coho is listed as 11.6 C by Tody (1973) and 12-14 C by Brett (1952); he also found upper lethal temperature for coho fry

to be 25.1 C. Our gillnet data for larger fish show maximum catch at 10-12 C, with a range from 2-18 C (Table B63). Seining data represent the small fish captured as 73-95 mm, and apparently they prefer considerably warmer temperatures as most were taken at 20-24 C, very near their upper lethal maximum. Some also were captured at 8-10 C.

TABLE B63. Temperature-catch relationships of coho salmon inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	—							—			.2±.1			
G		.1±.1	.1±.1		.5±.2	1±.8	.5±.3		.2±.2				—	—
T	—	—	—										—	—

Carp

Carp is one of several introduced exotic species in Lake Michigan. It was first recorded in the commercial catch of 1893, with annual averages of 6.8×10^5 kg (2.3 million lb) in 1966-70 (Wells and McLain 1973).

All carp captured were large individuals with a range from 134-832 mm (50-10,200 g). Most were adults 400-700 mm long. They were captured from April through October, most in June (19). They were most frequently captured with gillnets; seines were second in effectiveness. None were captured while trawling, indicating they can apparently avoid the trawl during both day and night. Considering just standard series data (Table B6), 14 carp were caught during June out of a total of 28 for the season. They represented 0.01% of the total number of fish captured. Carp were captured about equally at Cook and Warren Dunes during the day. More were captured at night at both locations, with 17 captured at Cook and only four at Warren Dunes.

Carp probably do not spawn in Lake Michigan in the vicinity of the Cook Plant. Gonad development data (Table B64) showed that a few ripe-running individuals were present in May and June; spent fish were present in August. However, a local resident near Grand Mere Lakes revealed that carp "during spawning season" oftentimes would be washed up on the beach if waves were high that day, where they could be easily speared. Swee and McCrimmon (1966) reported that spawning of carp in the Great Lakes is intermittent depending on temperatures and may extend from May through August. Scott and Crossman (1973) and others state that carp spawn in early spring and summer as the waters warm. Spawning does not begin in earnest until water temperatures

TABLE B64. Monthly gonad conditions of carp as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.								3	3		
Mod. dev.			1				1	1	2		
Well dev.				1	3				3		
Ripe-running											
Spent							1				
					Males						
Poorly dev.					1		1	3	1		
Mod. dev.					3		7	5	3		
Well dev.		1	2	4	11	1	3	1	1		
Ripe-running				1	1						
Spent							1				
					Unable to distinguish						

are at least 17 C (McCrimmon 1968). Except a recent specimen about 125 mm long from a seine haul April 1974, we have never caught any of their young, which leads us to believe that at least in the Cook Plant area large carp either come from other areas in Lake Michigan or enter the Cook Plant vicinity from inland lakes, rivers and streams.

Perusal of temperature-catch data (Table B65) shows that carp were caught at a wide range of water temperatures from 8-24 C, with most caught at higher temperatures. Pitt et al. (1956) gave a final preferred temperature greater than 30 C for carp.

We observed large concentrations of carp in the thermal effluent in Lake Michigan at Big Rock Nuclear Plant in Charlevoix during June 1973 suggesting that carp may also concentrate in the thermal effluent of the Cook Plant. However, the Big Rock discharge is in a canal on shore, while the Cook discharge is at 6.1 m (20 ft) and utilizes jet diffusers which should dissipate the waste-water more quickly. Similarly, tagging studies on 13 and 15 June 1973 at the Palisades Plant, which also has an onshore discharge canal, showed high concentrations of carp in the thermal plume (Consumers Power Co. 1972). The local population of carp was estimated to be between 1000 and 3000 in the areas of the discharge on any one day in late June while the thermal effluent was present. This estimate is thought to be low, since hundreds of carp were seen and not marked. Nowhere else in the immediate

TABLE B65. Temperature-catch relationships of carp inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done and blanks indicate no fish were caught at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	--				$.1 \pm .08$	$.1 \pm .1$		--			$.7 \pm .3$	$.4 \pm .2$		
G							$.5 \pm .6$	$.1 \pm .2$				2 ± 1	--	--
T	--	--	--										--	--

area of Palisades were carp as abundant as in the discharge.

Chinook Salmon

Chinook salmon were stocked in Lake Michigan in 1967; by the end of 1970, 4.1 million fingerlings had been released (Wells and McLain 1973). The sport fishery harvested 170,000 of these fish in 1970. Growth of chinook in Lake Michigan is estimated as follows: age II ranged from 61.2-64.0 cm (24.1-25.2 in); age III, 86.9-98.8 cm (34.2-38.9 in); age IV 98.6-98.8 cm (38.8-38.9 in) (Tody 1973). Chinook salmon, age 0, are planted in the spring when they are 51-76 mm long and 4-5 months old (Parsons 1973). Spawning runs that develop are usually composed of II- and III-yr old fish. Rarely do chinook reach age V.

We caught 26 chinook salmon in standard series fishing efforts (Table B6), most during May (5) and June (6). None were captured in February, November and December. Most were caught in gillnets and seines, one in a trawl. During the night (18) were caught, during the day eight. Range in size of all chinook caught was from 69-934 mm (2.7-8640 g), with the 200-mm size group being most abundant. Small fish 69-96 mm were seined during May and June only, with one small fish captured in a trawl. Thus, like coho, which were most abundant in the beach zone in June, some small chinook also prefer inshore waters during late spring.

Our gonad data (Table B66) are inadequate to show spawning, but it is known that chinook salmon spawn in the fall usually in rivers. It is thought that the St. Joseph River, about 18 km north, attracts most chinook salmon in the area during the spawning season.

Preferred temperature of YOY and yearling chinook salmon is 11.7 C (Ferguson 1958). Considering our field data, adults were captured over the range 4-16 C, with 12-16 C having highest catch (Table B67). Smaller fish 69-96 mm caught in seines were taken at 6-8, 10-12 and 20-24 C, indicating a broader range of temperature tolerance than indicated in the literature.

TABLE B66. Monthly gonad conditions of chinook salmon as determined by inspection and classification of the state of development of ovaries and testes. Fish were captured during 1973 in southeastern Lake Michigan. All fish examined in a month were included except immature and poorly received specimens.

Gonad condition	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Females						
Poorly dev.							1				
Mod. dev.											
Well dev.											
Ripe-running			2	1							
Spent											
					Males						
Poorly dev.				2							
Mod. dev.								2	1		
Well dev.							2				
Ripe-running											
Spent											
					Unable to distinguish						

TABLE B67. Temperature preference of chinook salmon inferred from mean catch over 2 C temperature intervals in seines (S), gillnets (G) and trawls (T). Standard error is also given. Dash means no fishing was done at that temperature.

	Mid-point of 2 C temperature interval													
	1	3	5	7	9	11	13	15	17	19	21	23	25	27
S	--			.1±.1		.2±.2		--			.3±.1	.1±.07		
G			.2±.1	.2±.2	.1±.1	.2±.2	.5±.2	.5±.3					--	--
T	--	--	--							.1±.1			--	--

Gizzard Shad

As a result of their migratory habits, gizzard shad entered Lake Michigan possibly through the Chicago River Canal and were first noted in 1953 (Miller 1957). They are a common species in Lake Erie (Scott and Crossman 1973; Parkhurst 1971). Shad reach the northern limit of their range in the Great Lakes, being much more common and abundant in rivers and large reservoirs farther south. Spawning occurs in spring and early summer and was specifically recorded by Bodola (1964) in Lake Erie on a sandy, gravelly bar in temperatures of 17.2-22.8 C. Following spawning, fish return to deeper water. Eggs hatch in 95 hr at 16.7 C (Miller 1960). Females averaged the following standard lengths at respective years of age in Lake Erie: age I, 140 mm; II, 285 mm; III, 335 mm; IV, 366 mm; V, 390 mm (Bodola 1964). Gizzard shad are abundant in Lake Erie where they far outnumber alewives, and their abundance in Lake Michigan appears to be increasing from our limited sampling in 1972 (one was caught). They may be another indicator of the increasing eutrophication of Lake Michigan which, as in Lake Erie, might favor gizzard shad survival over alewife.

In standard series fishing we caught 23 gizzard shad, all from seines, one in October and 22 in November. Of these, 6 were caught during the day, 17 at night. They ranged from 52-130 mm (1.1-23.5 g). According to Lake Erie standards (Bodola 1964) these fish were probably YOY and appear to be quite abundant along the entire shoreline relative to previous year's data when only one fish was caught (Jude et al. 1973).

In total fishing we caught 40 individuals, one in January, one in March and the rest from September to November. Sex ratio of the unadjusted standard series catch was 13 females to 3 males with 3 undetermined. The largest of these was a 494-mm (1500-g) female. The largest catch of shad in supplementary fishing came from a gillnet set at station C in September, when five females ranging from 415-450 mm were captured. A similar catch at station A, also supplementary fishing, was recorded during October, when five females ranging from 356-445 mm were taken. These fish were almost 100 mm longer than Lake Erie shad (Bodola 1964); Trautman (1957) cited 521 mm as maximum size of fish captured in Ohio. Gillnetted fish were caught at the 6.1-m stations, indicating a preference for inshore waters. Shad were taken from 8-18 C, with maximum catch (1 ± 0.5) at 10-12 C.

Ninespine Stickleback

The ninespine stickleback is found throughout the northern hemisphere in both fresh and salt water. Freshwater forms are scaleless, marine forms have small bony plates over portions of their bodies. The ninespine stickleback spawns in fresh water during the summer and has been reported to spawn more than once per season (Scott and Crossman 1973). It has an interesting reproductive behavior in that the male builds a nest of sticks and leaves and cares for the eggs and young. Maturity is gained by most individuals in their first year (Jones and Hynes 1950). They also reported the following length ranges per year class: age class I, 38-46 mm; II, 45-48 mm; III, 48-55 mm. Longevity is about 3.5 yr. Since they are scaleless, aging is done through use of otoliths. While not being of any direct use to man, they are reported

to be an important prey in areas where they have a high population (Dymond 1929). Dryer (1966) reported large numbers of ninespine sticklebacks occurring in Lake Superior. This abundance led to the supposition that their importance as a forage fish has been neglected. Wells and McLain (1973) indicate that ninespine sticklebacks have increased in abundance in southern and east central Lake Michigan in the past few years.

In our studies ninespine sticklebacks accounted for 0.01% of the total standard series catches for 1973. Total number caught was 19, with a range of 60-78 mm. Most fish were caught during May and June, 12 and five respectively. One fish was caught during March and April; none were caught in remaining months.

Almost equal numbers of individuals, 11 and eight respectively, were caught at Cook and Warren Dunes stations. There was, however, a difference in the numbers caught per fishing gear. Cook stations accounted for eight fish in seines and three in trawls as opposed to two in the seine and six in the trawl for Warren Dunes (Tables B7,8). None were captured in gillnets. Examination of catches on a day-night basis showed only one fish caught during the day, at station D in a trawl, and 18 at night. Examination of seine haul catches revealed little difference among stations. A comparison of offshore stations showed the majority of the catches were taken at 9.1 m. Four individuals were caught at station D, five at station H; 6.1-m stations accounted for one specimen.

Gonad data are sparse in terms of numbers of fish examined (Table B68). They do suggest an increase in the state of maturity toward summer, conforming to the reported general spawning season.

The ninespine stickleback was almost completely absent from the sampling areas during the day. No information on their movement was found in the literature; we suspect they may move offshore during the day and inshore at night. It is also possible that net avoidance during the day may play a role in catch differences.

Bluegill

Bluegills are a common inhabitant of inland lakes and ponds and have ready access to Lake Michigan via streams and rivers. They apparently do not adapt or fluorish in the ologotrophic lake environment as they were infrequently caught. In standard series operations 11 were taken during May through August and November (maximum catch of five). Nine were caught at night, two during the day, nine with the seine and two with the trawl. Range in size of fish caught was from 33-95 mm (0.5-16.3 g). Two were females, the rest were immature.

Channel Catfish

The channel catfish is a freshwater species with a large natural range, extending over east and central North America from extreme southern Canada to northern Mexico (Scott and Crossman 1973). Introductions have been made west

TABLE B68. The sex and gonad condition and the number of each (in parenthesis) recorded from seldom cpatured fish in the Cook Plant vicinity, southeastern Lake Michigan. F = female, M = male, X7 = undetermined sex, see methods for definition of gonad conditions.

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mottled sculpin			(2)M2 (5)F3	(1)F2	(1)F5 (2)X7				(2)M1		(2)F3
Lake whitefish		(1)F2			(1)M2 (1)X7					(1)F5	
Black bullhead			(1)M1 (1)F1 (3)F2								
Quillback carpsucker									(1)F2 (1)F5		
Channel catfish				(1)M2	(1)M5		(1)M5 (1)F5	(1)M1 (1)F5	(2)F1	(1)M1	
Burbot		(1)M3	(1)M2 (2)M3 (1)F5		(2)F5						(2)M3 (1)F3
Rock bass					(1)F3						
Bluegill					(2)F2						
Lake sturgeon			(1)X7			(1)X7					
Largemouth bass			(1)F3				(1)M1				
Round whitefish									(1)M2		
Ninespine stickleback	(3)F1	(1)M1	(1)F3	(1)F3 (8)F3 (1)M1 (1)M2 (1)M3	(5)F3						

of the Rocky Mountains. The channel catfish is an excellent gamefish which is often overlooked in its northern range. In its southern range it is widely fished and prized for its flesh. It is also an excellent species for pond culture and is extensively farmed in southern United States.

Our standard series of nets accounted for 11 channel catfish making up 0.01% of the total catch. Three fish were caught in seines, seven in gillnets and one in a trawl. Total length ranged from 163-651 mm. Two individuals were taken during the day and nine at night. Channel catfish are known to be more active during the night than the day. Gonad data show spent males and females occurring in June, August and September (Table B68). Scott and Crossman (1973) report the spawning season from late spring to summer.

Burbot

Burbot have never been important commercially in the Great Lakes (Wells and McLain 1973). Reduction of burbot to very low numbers by the late 1960's has been attributed to sea lamprey predation; with control of lampreys they are increasing. Burbot spawn from January to March in Canada (Scott and Crossman 1973). Our gonad data confirm winter spawning, as the two males and one female caught in December (Table B68) at station A were ripe, and burbot eggs were found in beach fish larvae tows in January 1974. Scott and Crossman (1973) note there is circumstantial evidence that burbot spawn in deep water in some areas, but the spawning site is usually in 0.3-1.2 m of water over sand or gravel bottom in shallow bays or gravel shoals 1.5-3.0 m deep. Our data support shallow-water spawning. The actual spawning activity is said to take place in a writhing ball (10-12 individuals) only at night. Temperature is usually 0.6-1.7 C. Eggs hatch in 30 days at 6.1 C; young appear in late February to June. Maximum size in Canada is 937 mm fork length. In Canada and the Great Lakes the burbot is a resident of deep waters of lakes during summer, coming inshore only to spawn and sometimes remaining until late spring.

In standard series fishing (Table B6) we caught six individuals; three additional ones were caught in supplementary gillnets set at station A (Table B41). They ranged in size from 343-579 mm (254-1225 g); most were 400-500 mm long. All burbot were caught in gillnets. except one taken with a trawl at station G. Four were caught in April, two in June and three in December.

Optimum temperature for this species is 15.6-18.3 C with 23.3 C being its upper limit (Scott and Crossman 1973). Our gillnetted specimens were caught in water temperatures of 4-8 C and 16-18 C, the trawl-caught specimen in 18-20 C (Table B69).

Lake Whitefish

Lake whitefish stocks have been exploited in Lake Michigan for well over a hundred years. In the early years of maximum abundance they were captured using gillnets and beach seines. Decline of lake whitefish populations is reported to have started as early as 1850 (Wells and McLain 1973) and has

TABLE B69. Temperature-catch relationships as exhibited by mean catch at different temperature intervals for some seldom caught species of fish in the Cook Plant vicinity. (S = seine, G = gillnet, T = trawl; see Table B5 for definition of species abbreviations. Standard error in parenthesis is given for mean catches at each temperature).

Species	4-6C	6-8C		8-10C			10-12C		12-14C			14-16C	16-18C		18-20C		20-22C		22-24C	
	G	G	T	S	G	T	S	T	S	G	T	T	G	T	G	T	S	T	S	G
MS	.1 (.1)		.4 (.2)	.1 (.08)		.1 (.1)	.07 (.07)				.2 (.2)							.2 (.2)		
CC					.2 (.2)					.2 (.2)						.1 (.1)			.1 (.06)	.1 (.6)
NS				.1 (.08)		.3 (.2)	.4 (.2)	.1 (.1)				.1 (.3)					.3 (.1)			
LG															.1 (.1)					
LW								.1 (.1)						.3 (.3)						
BB				.1 (.05)													.1 (.09)			
BG				.1 (.08)	.2 (.2)	.1 (.1)													.2 (.1)	
BR	.2 (.1)	.4 (.2)											.2 (.2)			.1 (.1)				
LB				.2 (.1)																
RB							.07 (.07)						.2 (.2)		.09 (.09)					
PP									.2 (.2)										.04 (.04)	
GL				.06 (.06)																

been attributed to a variety of causes. Over-exploitation and degration of the environment, especially by sawmills on rivers, is thought to have played an important part (Koelz 1929). Decline in lake whitefish was first evidenced in the nearshore areas where they were once abundant. Lake whitefish is an excellent food fish and is praised for its flavor in the salted form. Spawning season varies greatly yearly and from lake to lake. In the Great Lakes region they spawn in late fall, usually November and December. Spawning does not occur until water temperature is approximately 7.8 C or lower (Lawler 1965). Eggs are distributed randomly in depths of 7.6 m or less over hard stoney or gravelly bottoms and sometimes on sand (Koelz 1929).

Three lake whitefish were captured during 1973. Two were taken during standard series trawling--one in May at Warren Dunes (6.1 m) and one in June at Warren Dunes (9.1 m). One fish was captured in June in a supplementary gillnet set at station E (21.4 m). Fish captured ranged in length from 195 mm (61.7 g) to 385 mm (573 g--male). Sex ratio of the total unadjusted catch was one male, one immature and one undetermined.

Black Bullhead

Black bullheads captured ranged in length from 87-140 mm (8.4-60 g). These fish are usually considered warm-water fish able to withstand adverse environmental conditions. In standard series fishing, two were caught in seines at station B, one in April and one in July. Apparently the sheltered nature of station B provides a habitat, at least temporarily, for black bullheads. The remaining four bullheads were taken from traveling screen collections in April.

Fathead Minnow

The fathead minnow, a commonly used bait for fish, is usually found in inland rivers, streams, ponds and lakes. Spawning occurs in spring and may extend into August; the male guards the eggs usually deposited by the female under rocks and logs (Scott and Crossman 1973). These minnows are short-lived, seldom surviving past 2 yr of age. The two fatheads we examined were immature individuals taken from seine hauls at station A, one 52 mm (1.4 g) during May and the other 47 mm (1.1 g) in July.

Rock Bass

Rock bass is another of our incidental species captured in the extensive sampling of the area. They are usually found in inland lakes and rivers and are fairly pollution-tolerant. Two were cpatured during 1973; one, a female 216 mm (256 g), was caught in a gillnet set at station G, 6.1 m, Warren Dunes in June, the other, 82 mm (10.8 g) was seined during November at station F, Warren Dunes.

Golden Shiner

Golden shiners appear to be extremely rare in the vicinity of the Cook Plant. These important bait fishes are usually found in inland lakes and are abundant in Lake Erie (Scott and Crossman 1973). They require vegetation and about 20 C for spawning.

We seined two individuals on 18 April, one at station F, Warren Dunes, and one at station A, Cook Plant. These specimens were 85 and 121 mm (4.2 and 13.5 g); sex was not determined. According to Scott and Crossman (1973), these fish probably would be about 2 and 4 yr old respectively.

Largemouth Bass

Largemouth bass are probably the best known inland lake predatory fish. They appear to be rare in Lake Michigan both historically and presently, though our data suggest they congregate in sheltered areas such as embankments and safe harbors in Lake Michigan.

We caught one, a large gravid female 468 mm and 1625 g, in standard series fishing at station B, south of Cook, in a seine haul. Again the sheltered nature of station B as well as the seemingly favorable habitat for many other forage fish was probably responsible for its presence. We also caught nine small bass (range 131-291 mm) in a random seine haul inside the now defunct safe harbor.

Lake Sturgeon

In the early days of Lake Michigan fishery, lake sturgeon were exploited to a great degree, leading to complete protection of the species in 1929 followed by subsequent legalization again in 1951 (Wells and McLain 1973). This fish is on the endangered species list (U. S. Bureau Sport Fish. & Wildlife 1966). Overfishing and destruction of suitable spawning streams are probably responsible for its present low abundance. Since it takes 22 yr before it becomes mature (Van Oosten 1956), the species is acutely susceptible to overfishing. The Michigan Natural Resources Magazine for May-June 1974 cited the occurrence of a 140.6 kg (310 lb) sturgeon found dead near the Lake Michigan shore north of Benton Harbor.

The two specimens captured were taken in supplementary gillnets, one 410 mm long from station A in April (see Table B41), the other 865 mm from station D in July. Both were returned to the lake after measuring at time of capture, so no weight or sex data are available.

Lake Herring

Lake herring were the mainstay of the early commercial fishery in Lake Michigan and then declined considerably in abundance after 1908 (Wells and McLain 1973). Apparently this species undergoes great natural changes in abundance in all the Great Lakes but is now far less abundant than it once

was. Decline of herring in Lake Michigan has been attributed to the influence of smelt in the 1930's and of smelt and alewives in the sixties (Smith 1970; Wells and McLain 1973).

Spawning of large schools of lake herring occurs during times of falling temperature in late November and December, (Scott and Crossman 1973), usually in shallow water over gravel or stone but it may occur at greater depths of 9-12 m. Upper lethal temperature was found by Edsall and Colby (1970) to be 26 C.

The only specimen we captured was a 426-mm, 705-g female, gonads moderately developed but not ripe, collected at station E (21.4 m) on 6 February 1973 when water temperature was 1.7 C. A comparison with length and age data in Scott and Crossman (1973) indicates that this large fish was probably 9 or more yr old.

Quillback

Only two quillbacks, both females, 389 mm (807 g) and 501 mm (2220 g), were taken in 1973 in the same gillnet set in October at station L near the Grand Mere Lakes. This species is rare in the Cook Plant area.

Bowfin

Bowfin is another inland lake speices, often associated with stagnant water conditions. It is a unique predatory fish phylogenetically, being the only living member of an archaic group. Apparently there are a few which enter Lake Michigan, since we examined one male (357 mm, 408.5 g) from traveling screen catches of April 1973. None have been taken with our standard sampling gear to date.

Central Mudminnow

During 1973 only two mudminnows were caught, both from the traveling screens in March (4 C) and April (5 C), one 82 mm, 5.8 g, the other 79 mm, 6.1 g. Fish this size are probably 3-4 yr old. Mudminnows spawn in April at about 13 C (Scott and Crossman 1973).

Round Whitefish

Round whitefish have been abundant in Lake Michigan only locally (Wells and McLain 1973). Commercial production in Lake Michigan has been in the thousands of kilograms from 1893 to 1970. In North America this whitefish is found in all Great Lakes except Lake Erie. Only three detailed papers are available on round whitefish age and growth (Bailey 1963; Mraz 1964; Normandeau 1969). Spawning generally occurs in late fall, either over shallow reefs or in mouths of streams and rivers (Koelz 1929). Round whitefish are known predators of eggs, especially lake trout (Armstrong 1973; Scott and Crossman 1973). In studies conducted by Consumers Power near Ludington, Mich., on the

pumped storage project (Armstrong 1973), round whitefish were the sixth most abundant species caught with gillnets (370 analyzed), which indicates that these fish apparently are restricted to northern parts of the lake.

We caught one round whitefish on 23 October 1973 in a supplementary gill-net set at station L near the Grand Mere Lakes. It was a male, gonad moderately developed but not ripe, length 391 mm (563 g). According to Armstrong (1973), a fish of this size probably would be 4 yr old.

SECTION C

VERTICAL, DIEL AND SEASONAL DISTRIBUTION OF FISH LARVAE AND EGGS IN THE INSHORE WATERS OF SOUTHEASTERN LAKE MICHIGAN

David J. Jude and John A. Dorr III

INTRODUCTION

Fish larvae are an important and neglected life history stage of North American freshwater fishes. Year class strengths and the final species complex that eventually come to dominate any body of water first depend on the interactions of the egg and then the larvae with the environment and other organisms, especially other adults and fish larvae with which they cohabitate. Far too little research has gone into determining appearance and distribution of fish larvae, considering the importance of success in this stage of a fish's life. It is hoped that studies which we initiated and are continuing in the Lake Michigan environs will help to clarify some now cloudy areas of fish larvae biology, so that in understanding this important resource we may better protect it.

Our primary objective in fish larvae studies was to provide the necessary preoperational data from which effects due to thermal input and intake entrainment at a later date can be judged. We will attempt to establish the species, occurrence and density of larvae in the Cook Plant and Warren Dunes areas during day and night, horizontally with depth, vertically and seasonally.

Our secondary objectives were to 1) obtain complete information on all life history stages and confirm information, such as spawning times, derived from studies on adults and juveniles; 2) determine if the Cook Plant and Warren Dunes are spawning sites or nursery areas for fishes; 3) obtain field data on appearance of fish larvae so that a preliminary idea of densities of larvae that might be entrained can be ascertained, and 4) by consulting field data on the appearance and densities of fish larvae assist the temporal and spatial design of entrainment sampling.

It should be noted that normally only pelagic larvae and eggs were captured, because our sampling methods collect only eggs and larvae suspended in the water column. Demersal larvae and eggs may have been collected incidently because of currents or wave action stirring eggs and larvae from the bottom during or prior to sampling.

During 1974 we implemented three major efforts to correct deficiencies and answer questions unanswered during previous studies. The first was a change in design of the sampling program. We changed beach larvae tows so that two nets are pulled simultaneously in the same direction to eliminate variation. We will also perform discrete tows at the deeper stations rather than the steptow. Second, we added a fish-larvae sled towing device which we used at the beach stations and at deeper stations to sample demersal eggs and larvae. Third since we have had difficulty in identifying larvae, we initiated

a larvae rearing program so we can better obtain reference specimens of important larvae from a known source which are hatched and reared under known laboratory conditions.

METHODS

FISH LARVAE

A 1/2-m diameter nylon plankton net of No. 2 mesh, 351 micron aperature, was used to collect fish larvae, arbitrarily defined as any fish less than 2.54 cm total length. Samples from all seven standard series stations were collected during the day and at night once per month. Supplementary tows were performed at station E (21.4 m) and station M (6.1 m near the St. Joseph River). Four 5-min tows parallel to shore at an average speed of 3.2-6.4 km/hr (2-4 mph) were conducted at each deepwater station. These tows consisted of one 5-min tow each at 0, 1 and 2 m, and a single tow at deeper levels, as follows: 100 sec each at 3, 4 and 5 m for the 6.1-m stations; 100 sec each at 4, 6 and 8 m for the 9.1-m stations; and 100 sec each at 7, 13 and 19 m for the 21.4-m station. For inshore stations A, B and F a set of duplicate surface tow samples was obtained by towing the net by hand north to south, then south to north, a distance of 30.5 m (100 ft) once during the day and once at night in a depth of 0.8-1.2 m (3-4 ft). Samples were immediately preserved in 10% formalin.

A flowmeter attached to the center opening of the net indicated volume of water sampled. Flowmeters were calibrated by four people pulling a 1/2-m ring horizontally with and without the net 13.3 m four times each in an indoor swimming pool. Efficiencies (ratio of volume of water filtered with the net to volume of water filtered without the net) were calculated to be 84 and 92% for the two meters used. Each revolution of the flowmeter was calculated to represent 0.0170 m^3 or 17.0 ℓ of water filtered by the net per revolution of the flowmeter. Volume of water filtered at beach stations ranged from 1.7-6.6 m^3; for deepwater stations water filtered ranged from 0.8-32.4 m^3. Numbers of larvae captured were adjusted to number per 1000 m^3 by calculation to agree with published reports (Wells 1973) and to avoid reporting less than whole numbers of larvae. The flowmeter was unavailable for some beach station tows. In these cases an average value of 3.96 m^3 (233 $\pm$ 10 revolutions, N = 28) was used. In one instance during deepwater tows, an average value was used (14.0 m^3 - 826 $\pm$ 36.8 revolutions, N = 63) because a leaf had been caught in the meter. During April and May the 1000's indicator was missing from the flowmeter. Flowmeter readings for June and July were averaged, and two standard deviations on either side of the mean were calculated to be 242 and 1410 ($\bar{x}$ = 826). From these data we concluded that all readings less than 242 in April and May should have had a 1000 appended to them, and this was done for nine flowmeter readings.

Numbers of larvae captured in the steptow represent an "average value" for the various depths over which the net was towed and are comparable to values obtained from the 0, 1 and 2-m tows, since the net was towed for 5 min as was done with the other tows. Because the net when brought from lower levels passed through the water column above, total numbers captured per

steptow were adjusted by calculation to compensate for this upper strata contamination. Through swimming pool tests, towing the net vertically in 2.6 m of water, we determined that the net filtered 0.476 m^3 (28 ± 0.52 revolutions) of water or 0.18 m^3 for each meter of water through which the net passed. Numbers of fish larvae that would have been captured if 0.18 m^3 were filtered at each of the depths were calculated. Then numbers of fish larvae caught at 1 m, 2 m, and the steptow were adjusted by subtraction to account for larvae caught while passing through upper layers, then multiplied by a factor to get the catch in terms of numbers per 1000 m^3.

Only alewives were depicted in length-frequency histograms for fish larvae since they were most frequently caught and presented enough data. A computer program was written to plot length-frequency histograms which used intervals of 0.5 mm, i.e., 1.6-2.0 mm, 2.1-2.5 mm, etc. Since duplicate tows were made for beach stations A, B, F, mean number of larvae in each length interval was plotted. Then one average, the number of fish per length interval averaged over each meter of water, was desired for comparison with deepwater stations C, D, G and H. For 6.1-m stations this was accomplished by summing from each length interval the number of fish caught in 0 m, 1 m, 2 m and three times the number found in the steptow to represent 3, 4 and 5 m. In one case (station C June, the 1-m depth tow) 86 fish larvae were captured but lost before measuring. In this case we assumed the length distribution was the average of that found at the other three depths sampled. This appeared to be the case from examining length distributions over depths for other stations.

For 9-m stations, numbers in each length interval were summed by adding those caught in 0 m, 1 m, 2 m and six times those caught in the steptow to represent 3, 4, 5, 6, 7, 8 m. Numbers obtained were then divided by six or nine depending on station depth, and plotted, the numbers of larvae representing the average number of fish per 1000 m^3 averaged over the entire water column.

Analysis of variance, after a log + 1 transformation more closely approximated homogeneity of variance and normality, was used to test differences in catch of alewife fish larvae. Time of day, month, depth and station where the fish were caught were the main effects (treatments). See Section A for further discussion of techniques used.

FISH EGGS

Data on fish eggs came from two main sources--fish larvae tows and benthic ponar grab samples. Some samples were obtained also by SCUBA divers. Eggs from tows have not been identified to date, but identifications were inferred from spawning runs of adults where feasible. They are presented as numbers per 1000 m^3 using the same flowmeter methodology as discussed for fish larvae. Ponar samples will be analyzed at a future date.

RESULTS

FISH LARVAE

Fish larvae were most abundant during June and July; April and August

were months of lesser abundance (Table C1). No fish larvae were captured during March, October and November. A few smelt and alewife larvae were caught in May and September respectively.

Smelt were most abundant during April, the same month during which large numbers of spawning adults were captured in seine hauls at inshore beach stations. Interestingly no smelt larvae were captured at any beach station during April. Since we did capture some during 1974 studies in May it is believed that they do occur there just after hatching and probably migrate to deeper water where they grow larger. They were common at all open-water stations but were caught only during the night and were most abundant at 6.1 m, Warren Dunes. These larvae ranged in length from 4.1-7.1 mm total length with a mean of 5.8 ± 0.05 (N = 75). They were judged to be fairly young, since 1-day old specimens which we reared in the laboratory at 9 C were around 5.1 mm (N = 10).

Since weather, water temperature and other conditions were similar, and samples for these open-water stations were taken on the same day, the fact that no larvae were caught during the day must be attributed to either daytime net avoidance or some other behavior making smelt more susceptible to netting at night. Net avoidance seems unlikely since smelt were captured at deeper water stations, though in low numbers, and at beach stations during the day by us and by Wells (1973). At this time in May, smelt would be most likely to avoid a net. Larvae probably exhibit some type of vertical migration, being on the bottom during the day and near the surface at night in response to light or perhaps feeding behavior. If larvae were near or on the bottom during periods of daylight, our day tows would capture no smelt. Evidence for such behavior was obtained from our 1974 sled tows taken on the bottom during the day in May, when moderate numbers were found in samples. Also our diurnal 1974 entrainment sampling appeared to verify this hypothesis.

Numbers of smelt collected during April at stations C, D and H at all depths were similar, while numbers caught at station G, 6.1 m, Warren Dunes, were consistently higher. Little difference was seen among numbers of smelt caught at the various depths at a given station. For the remaining months, a few smelt were captured in May at stations A, C and D, in June at station B and in August at stations D and F.

Yellow perch were first captured in a night 1 m and steptow during April at 6.1 m, Warren Dunes. They were also captured at night during May at the north beach station at the Cook Plant. Our data indicate that peak spawning of yellow perch in the Cook Plant vicinity occurred within a very short time span, 1.5 weeks, starting around mid-June. Wells (1973) explained similar early occurrences of yellow perch larvae in Lake Michigan as having been hatched from spawnings in inland lakes and somehow entering Lake Michigan. In our samples, remaining yellow perch larvae were captured only in June and only at Cook Plant stations. They were captured in highest numbers at beach stations and were caught almost exclusively at night. No patterns in vertical distribution were evident at deep-water stations. Our inability to capture large numbers of yellow perch during the day was unexpected in view of those captured by Wells (1973) during June. In April, two perch larvae were caught, both 6.9 mm long. In May the only perch caught was 7.3 mm long. Mean length of the 19 caught in June was 6.0 ± 0.2 mm, range 4.4-7.5 mm. Thus it can be

TABLE C1. Number of fish larvae (<25.4 mm total length) per 1000 m^3 captured during 1973 in the Cook Plant and Warren Dunes vicinity. S = smelt, Y = yellow perch, A = alewife, SP = spottail shiner, X = unidentified, ST = steptow, dash indicates no sampling was done.

		March		April		May	
Station	Depth (m)	Day	Night	Day	Night	Day	Night
A†	0	0	0	0	0	286S ± 286	*253S ± 0
		0	0	0	0	0	*126Y ± 126
B†	0	0	0	0	0	0	0
F†	0	–	–	0	0	0	0
C	0	–	–	0	**147S	0	0
	1	–	–	0	62S	***71S	0
	2	–	–	0	77S	0	0
	ST	–	–	0	0	0	0
D	0	–	–	0	**285S	0	85S
	1	–	–	0	273S	0	0
	2	–	–	0	**102S	0	0
	ST	–	–	0	143S	0	0
G	0	–	–	0	**336S	0	0
	1	–	–	0	**753S	0	0
		–	–	0	** 54Y	0	0
	2	–	–	0	** 1214S	0	0
	ST	–	–	0	**425S	0	0
		–	–	0	** 56Y	0	0
H	0	–	–	0	0	0	0
	1	–	–	0	258S	0	0
	2	–	–	0	146S	0	0
	ST	–	–	0	70S	0	0
E	0	–	–	–	–	–	–
	1	–	–	–	–	–	–
	2	–	–	–	–	–	–
	ST	–	–	–	–	–	–
M	0	–	–	–	–	0	0
	1	–	–	–	–	0	0
	2	–	–	–	–	0	0
	ST	–	–	–	–	0	0

TABLE C1 continued.

Station	Depth (m)	June Day	June Night	July Day	July Night
A†	0	*9614A ± 5134	*3036A ± 506	*3795A ± 1518	*8222A ± 633
		0	*1265Y ± 126	0	0
		0	0	0	*630SP ± 630
B†	0	*1771A ± 506	*1898A ± 126	*26818A ± 20243	*6451A ± 1139
		0	*1134Y ± 567	0	0
		*506SP ± 506	*630SP ± 315	0	*630SP ± 630
		0	*126S ± 126	0	0
F†	0	*3036A ± 759	*2150A ± 126	*3795A ± 253	*10246A ± 1898
		0	*2898SP±1012	0	*256SP ± 256
C	0	3290A	5082A	0	1590A
		0	77Y	0	0
	1	9822A	1925A	0	2682A
	2	1897A	4079A	343A	2415A
		0	164SP	0	0
	ST	830A	5356A	965A	193A
		0	153Y	0	0
		0	153SP	0	0
D	0	649A	2176A	0	2200A
	1	6535A	1146A	0	1061A
		255Y	69Y	0	0
	2	1754A	1612A	560A	817A
		213Y	0	0	0
	ST	148A	653A	606A	346A
		0	210SP	0	0
G	0	954A	8946A	83A	528A
		0	142X	0	0
	1	444A	4592A	983A	267A
		65X	0	0	0
	2	526A	2853A	476A	623A
	ST	1264A	3037A	914A	480A
H	0	504A	1612A	720A	168A
	1	***309A	902A	133A	0
	2	289A	907A	186A	661A
	ST	313A	1637A	0	424A
E	0	68A	–	480A	–
	1	87A	–	0	–
	2	669A	–	109A	–
	ST	42A	–	448A	–
M	0	–	–	–	–
	1	–	–	–	–
	2	–	–	–	–
	ST	–	–	–	–

TABLE C1 continued.

		August		September		October	
Station	Depth (m)	Day	Night	Day	Night	Day	Night
A†	0	6463A ± 4077	1323A ± 385	0	0	0	0
B†	0	2820A ± 516	375A ± 375	0	0	0	0
F†	0	*14294A ± 4428	829A ± 406	0	*126A ± 126	0	0
		0	123SP ± 123	0	0	0	0
C	0	0	0	0	0	0	0
	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	ST	0	0	0	0	0	0
D	0	0	0	0	0	0	0
	1	68S	0	0	0	0	0
	2	0	0	0	0	0	0
	ST	0	0	0	0	0	0
G	0	0	372A	0	0	0	0
	1	0	72A	0	0	0	0
	2	52A	0	0	0	0	0
	ST	0	0	0	0	0	0
H	0	0	0	0	0	0	0
	1	133A	0	0	0	0	0
	2	0	552A	0	0	0	0
	ST	0	148A	0	0	0	0
E	0	99A	–	–	–	–	0
	1	345A	–	–	–	–	0
	2	0	–	–	–	–	0
	ST	0	–	–	–	–	0
M	0	–	–	–	–	0	–
	1	–	–	–	–	0	–
	2	–	–	–	–	0	–
	ST	–	–	–	–	0	–

TABLE C1 continued.

Station	Depth (m)	November Day	November Night	December Day	December Night
A†	0	0	0	-	-
B†	0	0	0	-	-
F†	0	-	0	-	-
C	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
D	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
G	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
H	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
E	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
M	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-

† represents the mean and standard error of duplicate samples.
* = mean value of 3.96 m^3 for amount of water filtered was used.
** = 1000 was added to flowmeter reading.
*** = mean value of 14.0 m^3 for amount of water filtered was used.

concluded that perch probably spawn through latter June in waters around the Cook Plant.

Spottail shiner larvae proved to be very difficult to identify and in the past were confused with yellow perch. Recently discovered distinguishing characteristics have ameliorated the problem. Spottail larvae were captured June through August, with June the month of maximum abundance. Since we believe spottail larvae spend most of their time on the bottom, their numbers here are undoubtedly underestimated. Our 1974 sled tow samples confirmed this, as large numbers of spottails were caught at night, particularly at most beach stations. In June, spottails with a mean length of 5.7 $\pm$ 0.1 mm (range 4.9-7.6 mm, N = 35) were caught exclusively at Cook stations in night step-tow and 2-m samples at 6.1 and 9.1-m stations. They were most abundant during day and night at the Cook south beach station, where the shallow nature of this habitat must have been favorable to spottails as a nursery area.

In July, spottails captured were 7.0 $\pm$ 0.9 mm (range 4.4-13.0 mm, N = 12), larger than those captured in June. However, presence of small larvae (4.4 mm) indicates hatching through July. Larvae were taken only at night from beach stations, and were more abundant at Cook than at the Warren Dunes station. In August one larva, 6.1 mm, was taken at night from the beach station at Warren Dunes.

Unidentified fish larvae (4.9 and 6.3 mm, N = 2) were caught at 6.1 m, Warren Dunes from the surface tow at night and the 1-m tow during the day.

We caught no trout-perch larvae in our larvae tows, although our unidentified larvae had some of the characteristics of trout-perch. Clarification must await laboratory rearing of specimens, which we hope to accomplish during 1975. We did capture 14 trout-perch in our trawling efforts on 26-27 October at stations C (6.1 m, Cook) and H (9.1 m, Warren Dunes), indicating that reproduction had occurred. These fish were YOY ranging from 12-18 mm and probably, like spottails, reside on the bottom and may be missed by our normal fish larvae sampling techniques.

Sculpin larvae were taken only incidently in a trawl haul at 20.4 m, station E, on 19 June 1973. Water temperature was 7.2 C. These larvae were just hatched, since eggs, eyed embryos and larvae were all in the same sample. It is not known what species these were, but most probably they were slimy sculpins. The spoonhead sculpin (*Cottus ricei*) was rarely caught by U. S. Fish and Wildlife Service personnel (Rottiers 1965), and the deepwater sculpin (*Myoxocephalus quadricornis*) is usually found in much deeper water. Neither fish has been captured during our sampling efforts. Spawning in riprap areas around intake and discharge structures in 1974 was also recorded by SCUBA divers (see Sec. B, sculpins). Rottiers (1965) has suggested that there may be two peaks in spawning by slimy sculpins, one in early spring by fish in shallow water, around 15 m or less, and another later on in the year in deeper water.

Alewife larvae were captured June through September, with June the month of maximum abundance. In all months, larvae were more numerous at beach stations than deeper-water stations. This was particularly evident

during August when larvae, mostly alewives, were highly concentrated in inshore waters. More alewives were caught during the day in August than at night. However, an analysis of variance (ANOVA) on data from the beach stations during June through August indicated there was no difference in numbers of alewife larvae caught between stations among months or between day and night. For offshore stations, an ANOVA for June and July showed a significant difference between catches of alewives at Warren Dunes and Cook locations, with the Dunes' stations having more alewife larvae (calculated $F = 5.27$; Tabular $F_{0.05}, (1,32) = 4.15$). No difference between numbers caught during day and night may be related to the fact that larvae are small and probably still lack sufficient ability to actively escape a net, because they are newly hatched in June (Fig. C1). They would be equally susceptible to netting during day and night if they exhibited no vertical migratory behavior. There appears to be a limited vertical migration upward by alewife larvae at night at stations C and D (not observed at G and H), since no larvae were caught in the upper layer, 0-1 m, during the day and yet that same night record high abundances were recorded at those depths (Fig. C2). It may be due also to the patchy distribution of this species.

Few alewives were caught at deeper-water stations in August, and no consistent patterns with regard to stations, depth or day-night variations were evident.

Alewife larvae captured during day and night sampling at beach stations in June (Fig. C1) were the same size. More larvae were caught during the day than at night, although this difference was not statistically significant. All small larvae caught in June at the beach stations were less than 10 mm (early post-larvae stage according to Norden 1967b), indicating they were still fairly young. Mansueti and Hardy (1967) stated that an alewife larva 5.15 mm T. L. was 5 days old. One can conclude that a large hatch of alewives, and thus spawning, occurred in early June in or near the beach area as hatching can occur within 3 days of spawning (Mansueti and Hardy 1967). Wells (1973) caught alewife larvae as early as 28 May in Lake Michigan off Saugatuck, but none in the Cook Plant vicinity.

Greatest numbers of alewives were caught during the day in June at station A, north of the plant; similar sizes but fewer fish were caught during the night. A similar pattern was observed at other stations. We concluded that net avoidance by these fish was negligible at this time. Mean size of larvae captured during the night was consistently smaller than that of larvae caught during the day at most stations, and many of the smallest individuals were caught only during the night. This suggests that perhaps newly hatched larvae stay on the bottom during the day and come to the surface only at night during the first early period of their lives. However, this pattern for small larvae was inconsistent in July.

In July, greatest numbers of alewife larvae were caught at station B during the day. At stations B and F few larvae greater than 8 mm were caught during the night whereas quite a number were collected during the day, indicating some type of diel movement by these larger larvae. In contrast, newly hatched larvae 2.5-6 mm were caught in approximately equal numbers during the day and night except at station F, where relatively large numbers of these small larvae were captured at night (2000-4000/m^3) compared with day

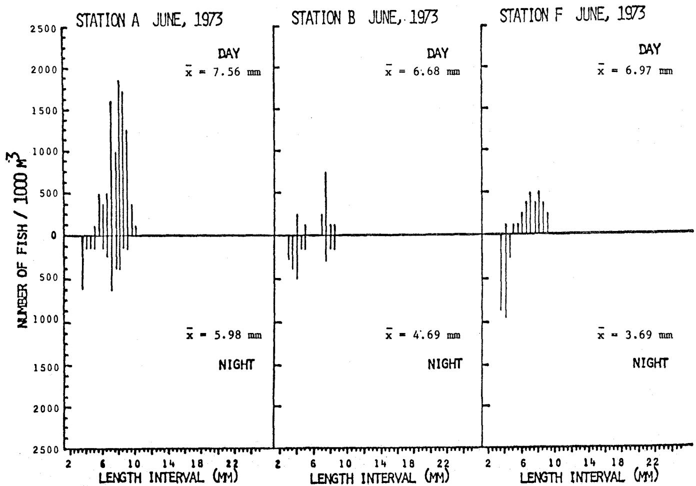


FIG. C1. Length-frequency histogram for larval alewives caught during day and night in June, July and August 1973 at beach stations in southeastern Lake Michigan. ($\bar{x}$ is mean length of caught specimens; alewife lengths from both duplicate samples were used).

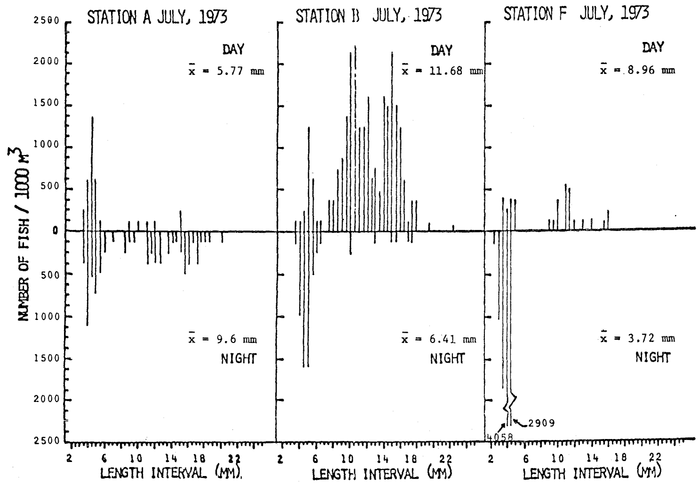


FIG. C1 . Continued.

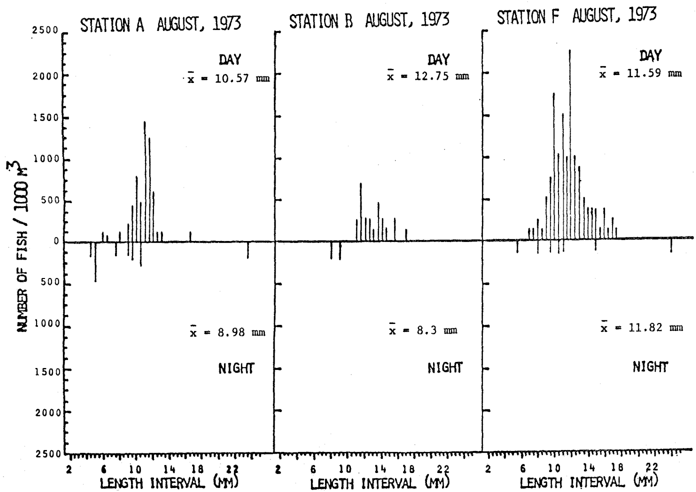


FIG. C1. Continued.

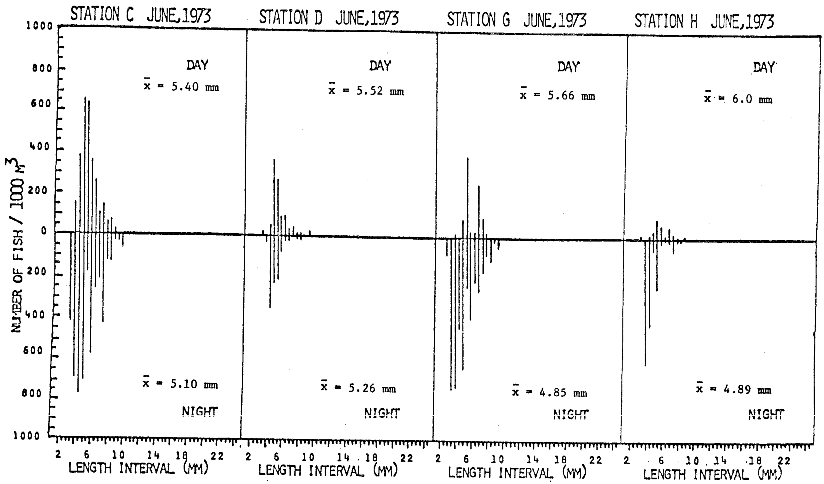


FIG. C2. Length-frequency histogram for larval alewives caught during day and night in June, July and August 1973 at 6.1 and 9.1 m stations in southeastern Lake Michigan. ($\overline{x}$ is mean length of caught specimens; alewife lengths from the four depths at each station were used).

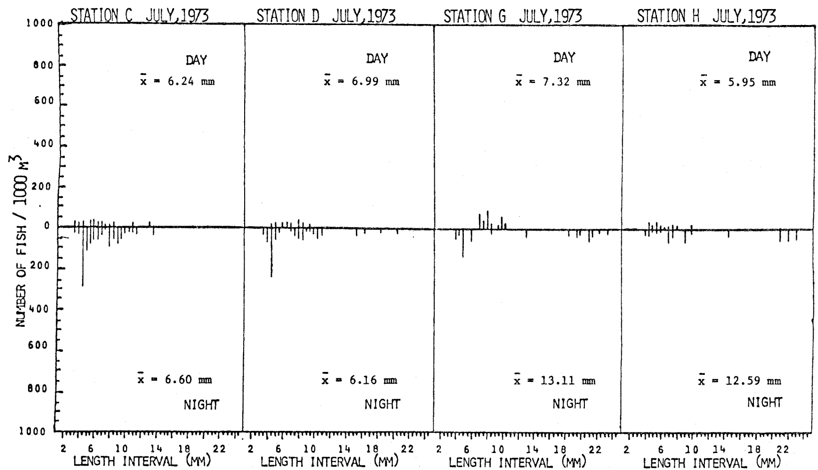


FIG. C2. Continued.

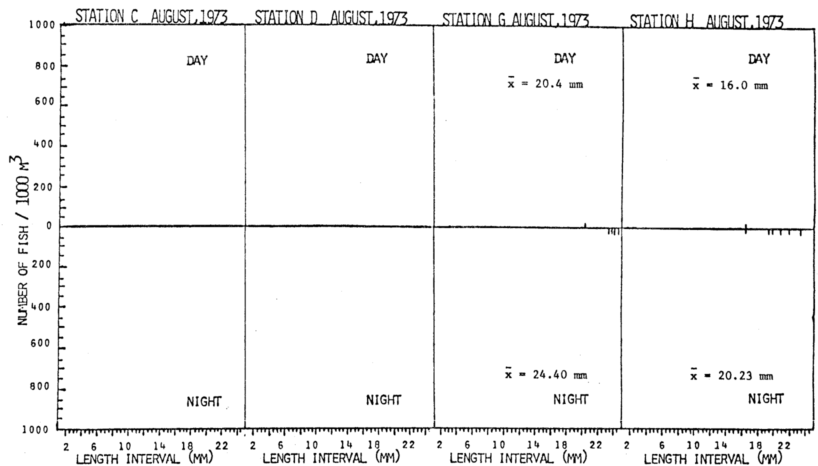


FIG. C2. Continued.

catches ($500/m^3$). Larvae in these large catches at beach stations in July were very small (Fig. C1) and could have hatched that same evening or the day before.

In August, alewife larvae captured were generally larger than those caught in previous months (Figs. C1, C2); however a few newly hatched larvae less than 6 mm were captured at station A, indicating that alewives have a prolonged spawning period lasting from June through August, a fact supported by examination of adult gonad data. At all stations, far more alewife larvae were captured during the day than at night, the same type of phenomenon observed in June and July, again indicating that net avoidance is probably not significant for alewives less than about 18 mm in length and that alewives are probably moving either outward or downward at night. Since few were caught at any depth at deeper water stations, one might conclude a downward migration was occurring during the night, at least at the inshore beach stations.

FISH EGGS

Fish eggs were observed in samples from April through September (Table C2). No eggs were collected in March, October and November. Eggs were almost always more abundant in beach station samples in a given month than at the deeper-water stations. This is probably related to the greater wave and current activity inshore but could be associated also with more spawning in beach-zone waters.

In April and May eggs were found only in beach station tows. They were collected in high concentrations at station A, $17{,}457/m^3$, during April in both day and night samples and were present at all beach stations during the night tows. These were probably smelt eggs, as we captured large numbers of gravid fish in seine hauls during April. Eggs collected around 15 May were probably smelt eggs also, since Wells (1973) stated his earliest collection of alewife larvae was on 28 May, thus probably ruling out eggs collected in May as alewife. In June through September very large numbers of eggs were recorded, probably most alewife. It was observed that yellow perch were eating large numbers of eggs during July, and that during one storm when wave height was about 1-4 m during larvae tows the highest concentrations of eggs were obtained. This indicates that a large concentration of alewife eggs probably lies on the bottom at least during July. In June most eggs were again collected at beach stations, though quite a number were collected from most depths towed at stations C, G (6.1 m) and H (9.1 m). In July, August and September, eggs were caught only at beach stations, except for two minor occurrences at deep-water stations. It would appear that these were mostly alewife eggs, and it is probable that by latter August and September most eggs were dead.

DISCUSSION

Net avoidance by fish larvae is an important consideration when evaluating distribution and occurrence data. Young alewife larvae did not appear to avoid the net to any great extent. For alewives greater than 10 mm there was a definite trend toward more being caught during the day than at night, suggesting that net avoidance is also minimal for these fish and that some

TABLE C2. Number of fish eggs per 1000 m^3 collected with horizonal No. 2 plankton net tows during March through November, 1973 in the vicinity of the Cook Plant and Warren Dunes.

		March		April	
Station	Depth (m)	Day	Night	Day	Night
A†	0	0	0	*17457 ± 17457	*1392 ± 1392
B†	0	0	0	0	*506 ± 506
F†	0	-	-	0	*253 ± 253
C	0	-	-	0	0
	1	-	-	0	0
	2	-	-	0	0
	ST	-	-	0	0
G	0	-	-	0	0
	1	-	-	0	0
	2	-	-	0	0
	ST	-	-	0	0
H	0	-	-	0	0
	1	-	-	0	0
	2	-	-	0	0
	ST	-	-	0	0
E	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-
M	0	-	-	-	-
	1	-	-	-	-
	2	-	-	-	-
	ST	-	-	-	-

TABLE C2 continued.

Station	Depth (m)	May Day	May Night	June Day	June Night
A†	0	0	*1138 ± 632	0	0
B†	0	14282 ± 9316	0	*25300 ± 22517	*53003 ± 33776
F†	0	0	0	0	*8982 ± 3162
C	0	0	0	0	770
	1	0	0	0	660
	2	0	0	0	164
	ST	0	0	0	0
D	0	0	0	0	128
	1	0	0	170	0
	2	0	0	0	0
	ST	0	0	0	0
G	0	0	0	0	42600
	1	0	0	195	6000
	2	0	0	0	0
	ST	0	0	0	9595
H	0	0	0	0	93
	1	0	0	0	8662
	2	0	0	0	1235
	ST	0	0	0	445
E	0	–	–	0	–
	1	–	–	0	–
	2	–	–	0	–
	ST	–	–	0	–
M	0	0	0	–	–
	1	0	0	–	–
	2	0	0	–	–
	ST	0	0	–	–

TABLE C2 continued.

Station	Depth (m)	July Day	July Night	August Day	August Night
A†	0	*2656 ± 2150	*90700 ± 11006	0	244 ± 244
B†	0	*1012 ± 1012	*2150 ± 126	139 ± 139	550 ± 550
F†	0	*2530 ± 759	*4029152 ± 982788	*380 ± 126	353 ± 141
C	0	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	ST	0	0	0	0
D	0	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	ST	0	0	0	0
G	0	0	0	0	0
	1	0	0	0	0
	2	0	0	174	0
	ST	0	0	0	0
H	0	0	0	0	0
	1	0	0	0	0
	2	0	0	0	0
	ST	0	0	0	0
E	0	0	-	0	-
	1	0	-	0	-
	2	0	-	193	-
	ST	0	-	0	-
M	0	-	-	0	-
	1	-	-	0	-
	2	-	-	0	-
	ST	-	-	0	-

TABLE C2 continued.

Station	Depth (m)	September Day	September Night	October Day	October Night	November Day	November Night
A†	0	0	*2777 ± 2777	0	0	0	0
B†	0	*253 ± 0	0	0	0	0	0
F†	0	0	*5313 ± 5313	0	0	-	0
C	0	0	0	0	0	-	-
	1	0	0	0	0	-	-
	2	0	0	0	0	-	-
	ST	0	0	0	0	-	-
D	0	0	0	0	0	-	-
	1	0	0	0	0	-	-
	2	0	0	0	0	-	-
	ST	0	0	0	0	-	-
G	0	0	0	0	0	-	-
	1	0	0	0	0	-	-
	2	0	0	0	0	-	-
	ST	0	0	0	0	-	-
H	0	0	0	0	0	-	-
	1	0	0	0	0	-	-
	2	0	0	0	0	-	-
	ST	0	0	0	0	-	-
E	0	-	-	0	0	-	-
	1	-	-	0	0	-	-
	2	-	-	0	0	-	-
	ST	-	-	0	0	-	-
M	0	-	-	0	0	-	-
	1	-	-	0	0	-	-
	2	-	-	0	0	-	-
	ST	-	-	0	0	-	-

†represents the mean and standard error of duplicate samples.
* = mean value of 3.96 m^3 for amount of water filtered was used.

sort of diel vertical migration was occurring. We seldom caught larvae over a certain species' specific size, suggesting that larvae rapidly attain the ability to detect and avoid a net, which Hogman (1971) discussed for whitefish larvae. An alternate hypothesis for explaining lack of larger smelt and perch in net catches is a demersal existence by these fish after they attain a certain size. The largest yellow perch and smelt caught were 8.0 and 7.1 mm respectively. A few odd catches of larger smelt, 17.6 and 23.8 mm, were made in June and August. Maximum size of spottail shiners in June was 7.6 mm, in July 13.0 mm.

Any conclusions with regard to migratory behavior either vertically or horizontally must be made in view of the above considerations. Larger alewife larvae were caught more often during the day than at night. This could be a phototactic response or related to feeding. Our 1974 sled tow data should clarify whether it does occur. Smelt were more common in the upper reaches during the night and apparently more toward or on the bottom during the day. We hypothesized that trout-perch, slimy sculpin and to a certain extent spottail larvae probably stay on the bottom for most of their early existence, since they were rarely or never caught in our larval tows.

The much discussed competitive influence of alewives on yellow perch (Smith 1970; Wells and McLain 1973) is a distinct possibility considering the great abundance of alewife larvae and adults at the time yellow perch larvae were also present. Alewife larvae were most abundant during June, July and August, particularly in beach-zone waters. Perch larvae were most abundant in inshore beach-zone waters during June. Smelt larvae occurred earlier in the year, before alewife larvae invaded inshore waters. Spottails and trout-perch spawn later in the spring and summer, the latter probably in deeper water. Spottail shiners are considerably more numerous than the once abundant emerald shiner (Wells and McLain 1973) and appear not to be adversely affected by the alewife, since spottails were the second most abundant species in the vicinity during 1973.

SECTION D

SUMMARY OF IMPINGEMENT AND ENTRAINMENT DATA

David J. Jude and John A. Dorr III

INTRODUCTION

The plant's circulation pumps were operated very little during 1973 because of difficulties in construction of the intake and discharge pipes as well as with various aspects of the pumps and associated equipment. Most pumping that was done was for testing equipment and for keeping the pumps from rusting and/or malfunctioning from disuse. Some difficulties in the mechanism for fish collections were encountered, so that fish were not consistently collected after pumping occurred. Pumping was performed with only one pump of seven, and the amount of water circulated was only a fraction of the eventual total water circulation. Therefore data collected were at best an indication of some of the amounts of species that might be encountered had continuous pumping occurred.

Limited entrainment sampling for fish larvae and eggs occurred only during February 1973, again due to the infrequent operation of the plant's circulation pumps.

METHODS

IMPINGEMENT

Cook Plant personnel presently separate fish from debris collected from the traveling screens, place the fish in a plastic bag, then tag and freeze them. Fish are thawed at the laboratory and processed in the same way as other fish, with an additional notation on the physical condition and degree of putrification.

ENTRAINMENT

A 303 ℓ/min (80 gal/min) diaphragm pump (actual capacity is 208 ℓ/min) with a hose extended to different depths in the intake forebay (1.5, 3.0, 4.6 and 9.1 m) was used to pump water into a 1/2 m No. 2 plankton net suspended in a 208 ℓ (55 gal) drum. Water flow through the drum was measured with a flowmeter. On one occasion a 1/2 m, No. 2 plankton net was suspended directly in the intake forebay. Samples were preserved with 10% formalin. No samples were taken from the discharge forebay. Sampling was performed primarily for the purpose of testing sampling equipment and procedures.

RESULTS

IMPINGEMENT

Of the 426 fish we processed during 1973, six species comprised 93% of the total number captured (Table D1). Slimy sculpin made up 29.6% of those captured, probably due to the fact that all pumping occurred during January, February, March, April, October, November and December--months when water temperatures were low. Our temperature data suggest slimy sculpin prefer temperatures less than 16 C. This, associated with the sculpin's natural attraction to rocky and dark places for concealment and spawning, apparently makes the species susceptible to this type of entrapment. Yellow perch comprised 25.8% of those caught and were almost all less than 100 mm. Spottail shiner, 13.4%, and smelt, 13.8%, were the next two most abundant species impinged. Alewife, 7.7%, and black bullhead, 2.8% (12 specimens), were the other fairly common species caught. Black bullheads are apparently more susceptible to pumping impingement than to our sampling methods, since we were able to capture only four during all our field sampling in 1973. Perhaps they are also attracted to the intake area like sculpins.

Twenty species were impinged, which is less than half as many as we captured during our regular field sampling activities. Bowfin, black crappie, pumpkinseed sunfish and mudminnow were four new species captured this year, taken exclusively from traveling screen catches.

ENTRAINMENT

A total of 16 diaphragm pump samples and one suspended net sample were obtained (Table D2). Upon laboratory examination no samples were found to contain either fish eggs or larvae. All samples were relatively free of algae, sand and organic debris.

From consideration of the fish larvae and egg data (Sec. C) which are given in terms of numbers per 1000 m^3, it can be seen that if an adequate sample is desired for determining entrainment effects, at least 10 m^3 for a sample of 10 larvae during months of maximum abundance should be filtered. For months of lesser abundance of common species of larvae and of rarer species, 200 m^3 or more should be sampled.

TABLE D1. An incomplete summary of fish impinged on the Cook Plant traveling screens from January through December 1973. This summary includes samples from eight of the 24 times pumps were operated between January and April 1973 because of technical difficulties beyond our control.

Date	Pump	Hrs. Pumped	AL†	BB	BC	BF	BR	CC	GS	JD	MM	MS	NP	NS	PS	SM	SP	SS	TP	WS	XC	YP
20 Jan.	11	3.90		1				3	1						1		2	5				4
	12	4.08																				
	13	4.10																				
31 Jan.	12	2.72		3	1		1	1										3		1		6
	13	3.30																				
5 Feb.	11	9.40														1		4				2
	13	4.35																				
15 Feb	11	9.40					1	1						1		23	26	8				18
	12	9.40																				
22 Feb	12	7.50																				
	13	7.50		2										4		26	17	18				5
15 Mar	11	6.23									1					3	1	5				1
	12	4.05																				
	13	6.38																				
4 Apr.	11	8.75	2	4						1	1					1	1	16				1
	12	8.75																				
19 Apr	12	2.00	1	2		1												34				
	13	2.00																				
10 Oct	*	*																2				
3 Nov	*	*														1		1			1	
15 Nov	*	*								1								2				
7 Dec	*	*										1						5				3
11 Dec	*	*										1	1									2
28 Dec	*	*	15													2		16				29
31 Dec	*	*	15					2				1				2	10	7	1			39

† See Table B5 for species abbreviation definitions.

* Requested pumping data have not been sent to us as of this date.

TABLE D2. Date, method of collection and duration of entrainment sampling conducted during February 1973 at the Cook Plant intake forebay. No fish larvae or eggs were found.

Date	Sampling method	No. of samples	Duration of sampling (minutes)
1 Feb. 73	Diaphragm pump	2	30
"	"	1	150
"	"	1	70
"	No. 2 plankton net suspended in forebay	1	80
15 Feb. 73	Diaphragm pump	1	5
"	"	8	15
"	"	1	30
22 Feb. 73	"	2	60

GENERAL SUMMARY

In our statistical section we tried to develop methods for treating the data composed of abundance indices for all important species and life history stages. Four gear types were used to gather the data and each has its own bias. All provide overlapping knowledge and are complementary to each other.

Trawl data were most amenable to statistical analyses because (unlike gillnets) duplicate samples were taken, and (unlike seines) no severe problems with bottom area covered were found. An ANOVA with fixed effects (model 1) was used to test for differences between numbers of fish caught at different stations, depths, time of day and months. We found zeros in the data matrix, a problem which we diminished by dropping months from the data analysis. A $\log_{10}(X + 1)$ was the best transformation for trawl data that we found. Trends in the relation of the size of catch in the first trawl haul, when compared to the second, suggested that currents as affected by weather patterns may be different in the two areas. We recommend that attempts be made not to sweep the same area twice when trawling. Efficiency of the trawl when fished with or against the current is unknown, so that trawling in opposite directions will increase variance in duplicate samples, but it was thought best to do that rather than sacrifice data already collected or try to set up radar reflectors at known distances and trawl by distance rather than by time as we now do. Least detectable differences were calculated for the five most abundant species, which for yellow perch showed that a two-fold increase or 50% decline in relative abundance of perch expressed as geometric mean number per trawl haul could be detected using 1 yr of preoperational and 1 yr of postoperational data. Someone must, however, decide what is detrimental to a given population, a task which we have chosen not to attempt based on 1 yr of data. It was found that all factors in the ANOVA--month, time of day, depth, area and year-- were necessary.

Gillnets were too long to be replicated; they should have been smaller and two duplicate sets made to be amenable to good statistical analyses. Replicate sets should have been made on different days, but upwellings and weather conditions could raise havoc with such replicates. Gillnets were set on the bottom and so are biased toward catching demersal fish. Beach seines sweep different areas depending on bars and depth. Plankton nets sample only pelagic small fish larvae and cannot be replicated on the MYSIS because of time/cost constraints. Flowmeter methodology was highly recommended to give accurate quantitative results.

Adult and juvenile fishes were the most prominent life-history stage, both from human interest and size. We captured 45 species through January 1974, five of which have been taken only from impingement samples.

Species associations observed at the Cook Plant study sites could be explained by a combination of the following factors: temperature, spawning acts, diel and foraging activities and upwellings. During an upwelling, alewives, spottail, trout-perch and to some extent yellow perch were forced out of the area, while lake trout, smelt, bloaters and sculpins tended to enter the area.

The various gear used appeared to catch the same percentages of fishes at both Cook Plant and Warren Dunes. Small fishes were caught mostly by seining and trawling, while larger fishes were caught by gillnets. More fish and a greater diversity of fishes were taken at night than in day sampling. Spottail and alewife were diurnal species, trout-perch nocturnal. The five most abundant species captured comprised 99.28% of all fish collected.

Alewives were the most commonly caught fish in the study area, comprising 76.40% of the total catch. Alewives are found in deeper water in the winter, migrate inshore in spring, disperse widely in warm summer waters and return to deeper water in the fall, closely following seasonal temperature changes. Alewife ANOVA contained many interactions among treatments showing the complex behavioral movements, diel, vertical, horizontal and seasonal, that alewives exhibit. Adults were predominantly caught during daytime and were most abundant during April and May, while YOY and yearlings were most abundant during August and September. Spawning occurs from late June through early August. Most alewives have migrated offshore by October. Adults captured in spring were caught in water 4-12 C, while a peak was also found at 16-22 C. Most YOY were caught at 16-20 C and 24-28 C.

Spottails were present in large numbers in the inshore waters of southeastern Lake Michigan during 1973. They prefer shallower depths, especially the younger fish. Few differences were found between catches at the control site and at the Cook Plant. Day beach seines caught large numbers of YOY and yearlings, while night trawl and gillnet catches were consistently higher than day catches. Spawning occurred in shallow depths in June and July and was observed by divers to occur on intake crib structures. Compared to spottails from other habitats, growth is slow in the first year of life, perhaps from competition with alewife. Later, growth is rapid, probably a result of decreased competition for food and absence of predation. Spottails first enter inshore waters in spring, move within the 6.1-m zone in June and July and then move out to deeper waters by late summer. Some remain inshore (6.1 and 9.1 m) for most of the winter months. YOY spottails are thought to remain on the bottom and near beach zone areas. Temperature-catch data showed spottails to be most often caught at 6-12 and 16-22 C. A diseased condition of some fish was noted.

Smelt adults come inshore to spawn at night in April and May when large numbers were taken by seining. Spawning temperatures were 8-10 C. Thereafter smelt retreated to deeper waters away from warm inshore temperatures. Adult smelt were virtually absent from the inshore environment during summer except during upwellings. A few were captured again in fall and winter when inshore waters cooled. YOY remained inshore for a short time after hatching, then migrated to deeper water (6.1 and 9.1 m). A vertical migration by YOY and yearling smelt off the bottom at night is suspected. YOY, yearlings and adults generally leave the area after September. Temperature of maximum catch of YOY and yearlings was 12-14 C; adults preferred 6-8 C.

Yellow perch are probably one of the most prized fish in the area because of their good taste. Adults first entered the area in small numbers in April and May, with June the month of maximum catch and probable spawning time. Most yellow perch were spent in June, indicating that spawning occurs outside 9.1 m or elsewhere in the lake. Perch are strongly diurnal, and exhibited

a distinct movement and a shoreward migration at night with retreat to deeper water by day. A gradual offshore dispersal occurred by October. YOY were found in the beach zone in July at a length of 25 mm, indicating their probable residence there through their early life. They were most abundant in beach zone larvae tows. YOY moved out to 6.1 and 9.1-m stations in August through October and probably deeper thereafter. Yearlings were abundant in beach zone water June through August; by August-September more yearlings were caught at 6.1 and 9.1-m stations, then wide dispersal in deeper water over winter occurred. Trawl-caught fish were taken most often at 22-24 C. YOY and yearlings were caught in water from 20-24 C, while large adult gilled fish were most often in water 16-22 C.

Trout-perch were abundant in the inshore waters of southeastern Lake Michigan during summer 1973. In late fall they migrated offshore to overwinter and return in spring. They are nocturnal in habit and dwell primarily on the bottom in all life stages. Few larvae were captured for this reason. In contrast to alewives and spottails, trout-perch do not utilize the beach zone to any great extent. There were no statistically significant differences between trawl or seine catches at the Cook and Warren Dunes areas. Spawning probably takes place from May to September, peaking in June and July. Growth is slow during the first year of life, but in southeastern Lake Michigan older fish attain very large sizes, possibly larger than in any other habitat in the Great Lakes region from which trout-perch have been reported. Trout-perch in the study area are not preyed upon by piscovores to any extent but could become important forage species, especially for lake trout, if alewife numbers declined drastically. Most trout-perch were taken when water temperature was from 14-20 C with a peak at 16-18 C.

There were a number of less abundant species. Johnny darters, a demersal fish caught mostly in trawls, were the sixth most abundant fish caught in the area; they were most abundant in May and June. White suckers spawn in the spring in rivers; we captured no YOY or yearlings. They appear to be a nocturnal species with highest catch at 12-16 C. Lake trout, a native and important sport and commercial fish, are now abundant in the study area, compared with recent lows in their population levels due to lamprey predation, commercial exploitation and spawning ground degradation. They spawn in the fall, and present populations are all from stocked specimens. They are nocturnal species with pronounced longshore movements. They prefer cold temperatures with peak catch occurring at 12-14 C. Bloaters are a commercially important coregonid which appear to be increasing slightly from all time lows in population numbers. They were caught from July to November, with July the month of maximum catch. They are associated with cold water and come in with upwellings in July through September. They are a deep-water fish which spawn in winter in deep water. They were caught when water temperatures were 6-20, with peak catch at 12-14 C. Longnose suckers were caught mostly in gillnets and spawn in April in rivers. They are a nocturnal species with peak catch at 10-14 C.

Rainbow trout spawn in fall and winter. Juveniles were caught in beach-zone waters during summer, while adults were taken in gillnets during fall and spring. Adults were caught in 4-12 C water, juveniles most often at 10-12 and 24-26 C. Sculpins, mostly slimy, were most abundant during April and May when spawning usually takes place. They spawn under rocks and logs, and

divers recorded their spawning on riprap areas around the intakes. Some difficulties in distinguishing between slimy and mottled sculpins was experienced. Sculpins are nocturnal; most were caught in trawls and many were impinged. Most brown trout were caught in June. They are nocturnal and most caught were juveniles. Larger browns were taken by gillnet in the spring and fall, while juveniles were captured in the beach zone while seining. Large fish were caught at 6-16 C while small fish were taken in 4-26 C waters. Emerald shiners are rare in the area, all 49 were taken in seines. They were caught in the 26-28 and 18-20 C ranges.

Coho salmon appeared not to concentrate in the area and were most often caught at night in May and June. Many small fish were seined in June, and larger ones, 500 mm, were taken in gillnets in the fall. They spawn in the St. Joseph River. Carp were all large mature individuals, with most being taken in June in gillnets. No spawning occurred at Cook Plant areas, and they could be a problem species as they tend to concentrate at warm-water plumes at other plants. Chinook salmon were caught most often in May and June. They spawn in the fall and do not concentrate in the Cook Plant area. Small seined chinook had a higher temperature tolerance than mature individuals. Gizzard shad are rare in the area but seem to be increasing in the vicinity of the plant compared to previous catches in 1972. Ninespine sticklebacks were most abundant in seine hauls in May and June. Two lake sturgeon were caught and released. A large number of other incidental species were also taken.

Fish larvae were most abundant in June and July and less so in April and August. None were caught in March, October and November and only a few were taken in May and September. Smelt larvae were abundant during April 1973 and May 1974 due to later spawning in 1974. They were found at beach stations after hatching and then at deeper-water stations, 6.1 and 9.1 m. They are nocturnal in behavior and appear to migrate upward during the night. Yellow perch larvae were first caught in April and May and thought to be inland lake escapees. Perch were most abundant in beach-zone tows in June; most were caught at night exclusively at Cook Plant stations. Only small larvae were captured. Spottail shiner larvae were found June through August with June being month of maximum catch. They were most commonly found at night at beach stations and lower depths of the deep-water stations and primarily at the Cook Plant. Trout-perch 12-18 mm were caught only with trawls in October, indicating a demersal existence, a phenomenon also found for slimy sculpin larvae. Alewife larvae were the most abundant species, being present in samples from June through September. They were most abundant at beach stations particularly in August, and more were generally caught during the day than at night.

Smelt eggs were common at beach stations in April and May. June through September samples contained high numbers of eggs suspected to be those of alewife.

During 1973, with limited pumping, 426 fish were impinged at the Cook Plant. Slimy sculpin comprised 29.6%, yellow perch 25.8%, spottails 13.4%, smelt 13.8%, alewife 7.7% and black bullhead 2.8%. Twenty species were impinged, four of which were captured only via impingement.

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